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EFFECTS OF RECONSTRUCTION SURGERY AND INDIVIDUALISED REHABILITATION ON NEUROMUSCULAR, SENSORIMOTOR AND MUSCULOSKELETAL PERFORMANCE IN PATIENTS WITH ANTERIOR CRUCIATE LIGAMENT DEFICIENCY

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AUTHOR'S DECLARATION

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Submitted by Christopher Yates to Queen Margaret University (QMU, Edinburgh) as thesis of the degree of doctor of philosophy in rehabilitation sciences (physiotherapy)

In October 2016

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Signature: ………………………………………………………………..

DEDICATION

I would like to dedicate this work to my family and friends who have helped at various points over the past seven years. In particular, my mother, who without her financial support during hard times, I would not have been able to carry on with my studies. Her continual presence has seen me though this challenging chapter of my life. Whilst finalising this thesis, I was grateful for the birth of my little girl. Although this time was difficult and I experienced many sleepless nights, having her made the final strive to the end a more enjoyable process. For this, I dedicate this thesis to Celia; my greatest love.

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Completing a PhD has been a truly marathon event. This doctoral programme of research has been an emotional rollercoaster with many highs and lows, and I consider it my greatest personal achievement to date. I would not have been able to complete this journey without the help and support of countless people since beginning this doctoral programme based at Nottingham Trent University in 2007 to its completion at Queen Margaret University, Edinburgh in 2015.

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I am happy to say that another chapter in my life is now closed with the completion of this PhD. I hope new doors will open with new avenues to follow. In particular, I hope this research has clinical meaningfulness and helps further optimise physiotherapy practice which has kept me excited and motivated.

Lastly, I would also like to thank Sonya Mountford for her unwavering love, support and encouragement during the last year.

THESIS ABSTRACT

CONTEXT: Rehabilitation following Anterior Cruciate Ligament (ACL) Reconstruction (ACLR) benefits most patients electing ACLR surgery. Contemporary practice offers limited adaptation of the service to the needs of individual patients. This thesis focuses on a Randomised Control Trial (RCT) that evaluated the effects of a novel formulation of patient-centred musculoskeletal rehabilitation involving the Performance Profiling Technique (Butler and Hardy, 1992). Performance Profile Management (PPM), a programme of rehabilitation, was adapted to incorporate patient-physiotherapist negotiation and agreement on decisions for subsequent rehabilitation and treatment strategies. Therefore, the primary aim of the research was primarily to assess the efficacy of individually-tailored, self-managed rehabilitative care (PPM) in comparison to contemporary (CON) clinical practice. The latter would facilitate an understanding of patient needs and verify the circumstances in which rehabilitation might be enhanced by allowing individuals to play a key role in designing their treatment and recovery.

A secondary clinical aim was to evaluate the strength of relationships amongst Patient-Based Outcome Measures (P-BOMs) and Clinician-Based Outcome Measures (C-BOMs). Currently, it is unknown which combination of outcome measures (P-BOMs or C-BOMs) delivers an optimum global assessment of functional and physical performance capabilities during patients' post-surgical rehabilitation. A clinically-relevant and significant association amongst P-BOMs and C-BOMs might indicate correct scaling of patients' own capability perceptions with those measured using objective assessment methods (C-BOMs) and endorse the utility for the clinical use of P-BOMs.

OBJECTIVES: This eight-chapter thesis offers a series of studies delivering the thesis' objectives: A systematic review of the literature **(Chapter 3: Study 1)**, and three clinical research studies **(Chapters 5, 6** and **7**, respectively**)**. The first objective was to undertake a systematic review of the literature investigating the prevalence and to evaluate the strength of relationships amongst P-BOMs and C-BOMs used in contemporary clinical practice, in order to collate the best outcomes for the subsequent intervention RCT. A second objective involved undertaking a cross-sectional and longitudinal correlational evaluation of the strength of relationships amongst P-BOMs and C-BOMs at various assessment occasions (pre-surgery, 6, 12 and 24 weeks post-ACLR surgery) **(**secondary clinical aim: **Chapter 5: Study 2)**. A further objective focused on the delivery of a study **(Chapter 6: Study 3)** to assess the psychometric measurement properties of the Performance Profile. This outcome underpinned the clinical use of the novel intervention for individualised care with the subsequent RCT **(Chapter 7: Study 4)**. The latter RCT investigating the effects of the PPM intervention, was the culminating objective and addressed directly the thesis' primary clinical

aim. **Chapter 8** contains a general discussion, synthesising findings, limitations and future directions.

SETTING: Orthopaedic Hospital NHS Foundation Trust.

DESIGN AND INTERVENTIONS: **Chapter 7 (Study 4)** sets out a prospective random-allocation-to-group trial involving the effects of an experimental PPM intervention having been compared to those of contemporary (CON) practice (24-week musculoskeletal rehabilitation programme). All participants elicited an individualised Performance Profile within a two-week period prior to their ACLR. Based upon routine evaluation of Performance Profiles, the care delivery pattern and content of the conditioning was modified periodically through patient-physiotherapist negotiation, to optimise attainment of the desired improvements.

PARTICIPANTS: Forty-six patients (41 males [age at surgery (years): 31.6 ± 12.7 (range 16 to 63); height (cm): 176.3 ± 5.1; body mass (kg): 80.5 ± 9.1]; 5 females [age at surgery (years): 28.0 ± 11.7 (range 16 to 43); height (cm): 162.1 ± 4.3; body mass (kg): 64.2 ± 8.9]), electing to undergo unilateral ACLR surgery (central third, Bone-Patella Bone-Tendon (BPBT) [n = 3], or Bone-Hamstring-Tendon-Bone (BHTB) [n = 43]) were randomly-allocated to two rehabilitation groups (PPM; CON) and assessed on four separate assessment occasions (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery). Twelve patients (of 58 recruited) had been lost to follow-up.

OUTCOME MEASURES: Overall knee function was assessed using the International Classification of Functioning, Disability and Health (ICF) Disablement Model framework, evaluated by P-BOMs (Visual Analogue Scale of Pain [VAS-Pain], The International Knee Documentation Committee (IKDC, primary outcome) Subjective Knee Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm Knee Score (Lysholm), and Performance Profile) and C-BOMs (Single-Leg Hop for distance, Anterior Tibio-Femoral Displacement (ATFD, knee laxity), Peak Force (PF: strength), Electromechanical Delay (EMD: time lag between the onset of electrical activity (electromyogram, EMG) and tension development in human muscle), Rate of Force Development (RFD: average rate of force increase of 25-75% of PF), and Sensorimotor Performance (SMP: ability to scale volitional force precisely [Force Error (FE)]).

RESULTS: **Chapter 5 (Study 2)**: Amongst several strands of findings, when P-BOMs were correlated with C-BOMs, only 317 of 2808 possible correlations (11%) were statistically significant ($p < 0.05$), with a small proportion offering clinical relevance ($r \geq 0.70 = 52$). The lack of correlation among P-BOMs and C-BOMs could potentially lead to sub-optimal conditioning within rehabilitation therapy, with patient's perceived capabilities being mismatched to the objectively-derived measurements.

Chapter 6 (Study 3): Following ACLR, patients perceived a 3.34-unit reduction in the injured limb (57.7% decrease in Performance Profile knee performance) compared to a 0.13-unit reduction in performance of the non-injured limb and illustrating the sensitivity and responsiveness of Performance Profile to detect post-ACLR changes in performance. Cronbach's Alpha and ICC results for the Performance Profile showed that over five consecutive trials involving random variations in performance, the assessed performance of both the injured (0.97 to 0.98) and non-injured limbs (0.95 to 0.96) indicated high measurement' reliability.

Chapter 7 (Study 4): Factorial analyses-of-variance (ANOVAs), with repeated measures showed non-significant group (PPM; CON [matched]) by assessment occasion interactions (pre-surgery, 6, 12, 24 weeks post-ACLR surgery) for all P-BOMs (VAS [Pain] ($F_{(1.1,50.2)}$ = 1.1, *ns*); IKDC ($F_{(1.1,50.2)}$ = 1.1, *ns*); Lysholm ($F_{(2.5,110.2)GG}$ = 0.29, *ns*); and KOOS [sub-scale scores: Symptoms ($F_{(3,132)}$= 0.9, *ns*); Pain ($F_{(3,132)}$= 0.5, *ns*); Function ($F_{(3,132)}$= 0.7, *ns*); Sport/rec ($F_{(3,132)}$= 0.3, *ns*); QoL ($F_{(3,132)}$= 0.9, *ns*)]) indicating congruency of effect over 24 weeks of rehabilitation for PPM compared to contemporary (CON) practice. A similar lack of group [PPM; CON] by leg [injured; non-injured] by assessment occasion [pre-surgery, 6, 12, 24 weeks post-ACLR surgery] interactions were noted for the C-BOMs (Single-Leg Hop for distance ($F_{(2,88)}$= 1.0; *ns*); ATFD ($F_{(1.6,73.3)GG}$= 0.3, *ns*); PF ($F_{(2.4,105.6)GG}$=0.8, *ns* [flexors]; $F_{(2.0,88.5)GG}$= 1.2, *ns* [extensors]); RFD ($F_{(2.4,105.6)GG}$=0.9, *ns* [flexors]; $F_{(2.0,88.5)GG}$= 1.3, *ns* [extensors]); EMD ($F_{(2.4,105.6)GG}$=0.6, *ns* [flexors]; $F_{(2.0,88.5)GG}$= 1.2, *ns* [extensors]); and SMP-FE ($F_{(2.2,100.4)GG}$= 1.5, *ns* [flexors])). SMP-FE associated with the knee extensors, offered a significant 3-factor interaction ($F_{(2.5,113.7)GG}$= 3.2, $p< 0.05$), which given the acknowledged causal importance of sensorimotor capabilities to avoidance of ligamentous injury, alluded to some degree of enhanced effect of the PPM intervention compared to control.

CONCLUSION: Limited statistical and clinically-relevant correlations amongst P-BOMs and C-BOMs suggest that each outcome potentially reflected important but separate, unrelated aspects of clinical response. Clinicians should be cautious about planning/progressing rehabilitation based on a single outcome measure, but instead, should continue to deploy multiple P-BOMs and C-BOMs. Patients' perceived capabilities were unrelated to objectively-derived measurements, and this lack of calibration could potentially lead to sub-optimal conditioning within rehabilitation therapy. Conclusions from the RCT were that the PPM matched the capabilities of 24 weeks of current rehabilitation practice to re-establish perceived and objective functional and physical performance in patients following ACLR surgery, while eliciting only slighter gains in Sensorimotor Performance. Thus, routine evaluation of Performance Profile facilitates effective, individualised care delivery patterns in which the content of rehabilitative conditioning can be modified periodically through patient-physiotherapist negotiation. In this respect, the Performance Profiling offers potentially an effective alternative to contemporary rehabilitative practice.

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ABBREVIATIONS

°/s: Degrees per second

⁝: Significant correlation at p< 0.001

†: Significant correlation at p< 0.05

‡: Significant correlation at p< 0.01

10PT: 10-Point Knee Rating Scale

ACI: Autologous Chondrocyte Implantation

ACL: Anterior Cruciate Ligament

ACLD: Anterior Cruciate Ligament-Deficient

ACLR: Anterior Cruciate Ligament-Reconstructed

ADL: Activities of Daily Living

ADLS: Activities of Daily Living Scale

ANCOVA: Analysis of Covariance

ANOVA: Analysis of Variance

ARS: Activity Rating Scale

ATFD: Anterior Tibio-Femoral Displacement

BASES: British Association of Sport and Exercise Scientists

Bi-POMs Bipolar Profile of Mood States

BHTB: Bone-Hamstring-Tendon-Bone

BMI: Body Mass Index

BPBT: Bone-Patella Bone-Tendon

CINCINNATI: Cincinnati Knee Rating Score

CSP: Chartered Society of Physiotherapy

C-BOM: Clinician-Based Outcome Measure

CM: Modified Cochrane Methods Group on Screening and Diagnostic Tests Methodology

CONSORT: Consolidated Standards of Reporting Trials

CV: Coefficient of Variation (%)

EMD: Electromechanical Delay

EMG: Electromyography

END-R: Endurance Ratio

ERAIQ: Emotional Responses of Athletes to Injury Questionnaire

ES: Effect size

♀: Female*

FAS: Functional Activity Scale
FAQ: Functional Ability Questionnaire
FE: Force-Error
Feagin & Blake: Feagin and Blake Knee Score
FORRS: Factor Occupational Rating System Scale
Global: Global Knee Score
H:Q: Hamstring and Quadriceps Ratio
HOP: Single-Leg-Hop Test for Distance
HRQOL: Health Related Quality of Life
HSS: Hospital for Special Knee Score
IAKS: Iowa Athletic Knee Rating Scale
ICC: Interclass Correlation Coefficient
IKDC: The International Knee Documentation Committee Subjective Knee Form
ITT: Intention to Treat
JPS: Joint Position Sense
KFR: Knee Function Rating Form
kg: Kilograms
KOOS: Knee Injury and Osteoarthritis Outcome Score
KOS: Knee Outcome Survey
KOS-ADL: Knee Outcome Survey with Activities of Daily Living Scale
Kujala: Kujala Knee Score
LCL: Lateral Collateral Ligament
LYSHOLM: Lysholm Knee Score
♂: Male
Marshall: Marshall Knee Scores
MARX: Marx Activity Scale
MCID: Minimally Clinically Important Difference
MCL: Medial Collateral Ligament
m: Metre
MDC: Minimal Detectable Change
MF: Micro Fracture
MIC: Maximal Isometric Contraction
MP: Mean Power
MVMA: Maximal Voluntary Muscle Activation
Nagi Model: Nagi Disablement Model
NHS: National Health Service

NCMMR: National Centre for Medical Rehabilitation Research Disablement Model
n: Number (i.e., number of patients)
Noyes: Noyes Knee Rating Scale
nr: No results found/reported
ns: Non-Significant Result
OA: Osteoarthritis
OAK: Orthopädische Arbeitsgruppe Knie Score
OXFORD: Oxford Knee Score
P-BOM: Patient-Based Outcome Measure
PCL: Posterior Cruciate Ligament
PCP: Personal Construct Psychology
PF: Peak Force
POMS-BI: Profile of Mood States Bipolar Scale
POPF: Post-Operative Physical Findings
PPM: Performance Profile Management
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PT: Peak Torque
QoL: Quality of Life
r: Pearson Product-Moment Correlation Coefficient
RCT: Randomised Control Trial
RFD: Rate of Force Development
RGT: Repertory Grid Technique
RJAH: Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry (UK)
ROM: Range of Movement
RPP: Reproduction of Passive Positioning
rs: Spearman Rank Order Correlation Coefficient
SARS: Sports Activity Rating Scale
SAS: Sports Activity Scale
SD: Standard Deviation
s: Seconds
SEM: Standard Error of Measurement
ST-GRA: Semitendinosus-gracilis graft
ST: Semi-Tendinosus graft
SF-36: Short Form-36 Health Survey
SMP-FE: Sensorimotor Performance
SPSS: Statistical Package for Social Sciences

SRM: Standardized Response Mean

TAE: Torque Acceleration Energy

TDPM: Threshold to Detect Passive Motion

Tegner: Tegner Activity Scale

TKR: Total Knee Replacement

TSP: Test for Substitution Patterns

TW: Total Work

VAS: Visual Analogue Scale

ICF: International Classification of Functioning, Disability and Health

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index

WOMET: Western Ontario Meniscus Evaluation Tool

Zarins & Rowe: Zarins and Rowe Rating Scale

T: Kendall Tau Rank Correlation Coefficient

PUBLICATIONS/CONFERENCE PROCEEDINGS

LIST OF PEER-REVIEWED ARTICLES AND CONFERENCE PAPERS ASSOCIATED WITH AND UNDERPINNING ASPECTS OF THE WORK WITHIN THIS THESIS

YATES, C., ALKITANI, A., DARAIN, D., BAILEY, A. AND GLEESON, N. (2016). Congruency and responsiveness of patient- and clinician-reported outcome measures of fitness following reconstructive knee surgery. Research Quarterly for Exercise and Sport (under review).

DARAIN, H., ALKITANI, A., **YATES, C**., BAILEY, A., ROBERTS, S., COUTTS, F., and GLEESON, N. (2014). Antecedent anterior cruciate ligament reconstruction surgery and optimal duration of supervised physiotherapy: A case report. Journal of Back and musculoskeletal Rehabilitation, 28 (2), p. 7-11.

GLEESON, N., ESTON, R., MINSHULL, C., BAILEY, A., ALKITANI, A., DARAIN, H., **YATES, C**., and REES, D. (2013). Effects of antecedent flexibility conditioning on neuromuscular and sensorimotor performance during exercise-induced muscle damage.
Journal of Exercise Science & Fitness, 11, p. 107-117.

MINSHULL, C., BAILEY, A., SHEPHERD, J., **YATES, C**., and GLEESON, N. (2013). Effects of concurrent versus non-concurrent rehabilitative conditioning in an ACL-reconstructed population, Barcelona, Spain. Conference: European Congress of Sport Science (26-29th June).

CHAPTER ONE

INTRODUCTION

1.1 - **Introduction**

The rehabilitation of a patient within a clinical setting often presents complex multi-factorial issues requiring various treatment interventions by different clinicians working within a multidisciplinary practice (Hurn, Kneebone, and Cropley, 2006). Within the field of rehabilitation, physiotherapists have the appropriate knowledge to manage many musculoskeletal disorders (Childs et al., 2005) and are the specialists who are required for the management of movement disorders and/or for dysfunction of neuromuscular-articular systems (Langendoen, 2004). Physiotherapists utilise a range of diagnostic and assessment procedures to develop and implement preventive and therapeutic interventions of care, following a patient's injury and/or surgery. Their role here is to analyse and classify a patient's functional disorder in daily life (disability/dysfunction) and, subsequently, to identify physical impairments that may possibly be related to the presented injury at the time of assessment (Gulick and Yoder, 2002).

In recent years, physiotherapy practice has encouraged healthcare professionals to become evidence-based (Langendoen, 2004) and they are continually required to utilise an evidence-based approach within their own physiotherapy practice (Huijbregts, 2005; Suter, Vanderheyden, Trojan, Verhoef, and Armitage, 2007). An evidence-based approach is broadly defined as the judicious use of the best current evidence to make appropriate decisions about the care of individual patients (Sackett et al., 1996). The concept and controversies of Evidence-Based Practice for rehabilitation professionals has been extensively reviewed (Dijkers, Murphy, and Krellman, 2012). In summary, when making treatment interventions, it is essential that all healthcare professionals integrate their own clinical expertise with respect to both the best available current research evidence and patient preferences and opinions (Straus, Richardson, Glasziou, and Haynes, 2005).

There is currently much interest in how an evidence-based approach can be applied within the field of physiotherapy. An important issue, which often overlaps with Evidence-Based Practice, is the concept of Patient-Centred Care (Bensing, 2000). At present, it seems unclear precisely what Patient-Centred Care should be adopted in physiotherapy practice and how physiotherapists can effectively integrate this approach into their own daily practices (Cooper, Smith, and Hancock, 2008; Ishikawa, Hashimoto, and Kiuchi, 2013). Moreover, there have been some concerns that Patient-Centred Care, which has focused on individualised perceived needs, might be at odds with an evidence-based approach which has tended to focus on populations as a whole and does not address individual patient preferences and perceived needs (Epstein and Street, 2011). Yet it can be argued that Evidence-Based Medicine should acknowledge that a good clinical outcome must be defined in terms of what is meaningful and valuable to the individual patient. Thus, Evidence-Based Medicine and Patient-Centred Care are intrinsically linked (Guyatt, Montori, Devereaux, Schünemann, and Bhandari, 2004).

In recent years, it has become clear that 'bridging the gap' between the paradigms of Evidence-Based Medicine and Patient-Centred Medicine is essential to optimising clinical outcomes (Bensing, 2000). Therefore, it has been proposed that randomised controlled trials, which are central to the concept of Evidence-Based Medicine, should include outcome measures that reflect patient preferences and perceived needs. For Patient-Centred Medicine, research should become more evidence-based by objectively and prospectively investigating different methodologies (i.e., effective communication strategies) in order to improve patient outcomes (Torgerson and Sibbald, 1998). Within the field of patient-centred care, effective communication is considered a central component (Bensing, Verhaak, van Dulmen, and Visser, 2000) and, recently, the combined concepts of both patient-centeredness and a shared decision-making process have been advocated as an optimal approach to the effective management and care of individual patients (Ishikawa et al., 2013).

With this in mind, healthcare professionals are to encourage patients to actively participate in, and share control of treatment and management decisions that take into account their individual preferences, opinions and values (Holliday, Cano, Freeman, and Playford, 2007). In a 'patient-centred care model' (**FIGURE 1**; p. 38**)**, the concept of patient-centred care is defined as an equal partnership between the clinician and patient (Wilson, 2009). Within this conceptual model, patient-centred care places the patient centrally within the professional relationship and, furthermore, supports the notion that an understanding of the patient's perspective should underpin good practice in an equal therapeutic relationship (Kidd, Bond, and Bell, 2011). Alongside this line of argument, the appropriate use of clinical reasoning and judgement in conjunction with a shared decision-making process are considered fundamental (Vranceanu, Cooper, and Ring, 2009; Smith, Higgs, and Ellis, 2007). Importantly, the concept of a shared decision-making process between a patient and a clinician has been reported to be an integral component in the effective delivery of patient-centred care (de Haes, 2006), and also specifically in the field of medical rehabilitation by physiotherapists (Faller, 2003).

In practical terms, for a physiotherapist to deliver true patient-centred rehabilitation, rehabilitation plans should be prospectively discussed with the individual patient during a goal-setting discussion. In this discussion, the patient's expressed needs, goals and expectations are identified and documented, with a view to informing decision-making processes on the rehabilitative care programme (Ozer, Payton, and Nelson, 2000; Wohlin-Wottrich, Stenström, Engardt, Tham, and Koch, 2004).

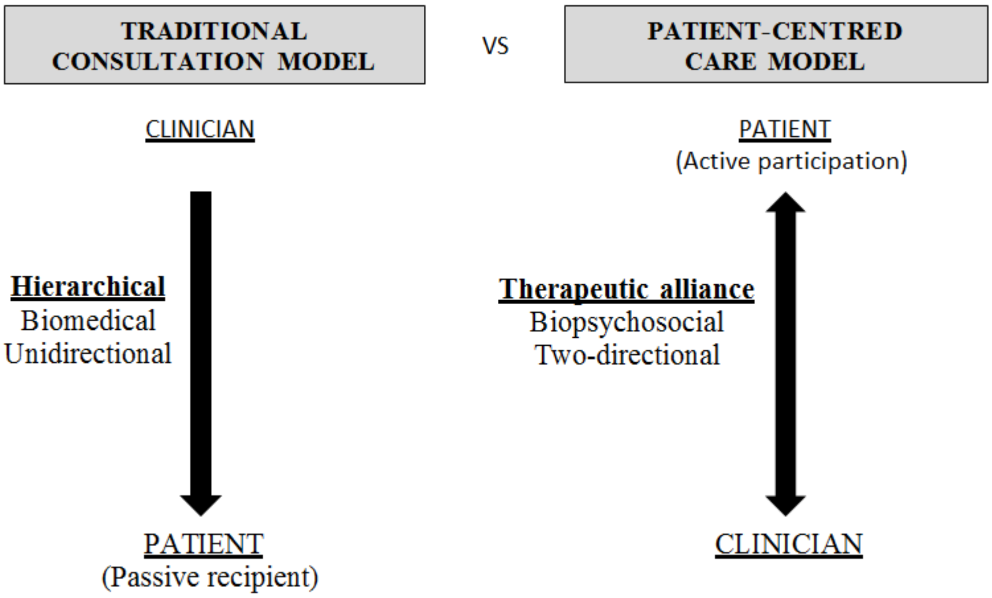

FIGURE 1 - Comparison of the patient-centred care model with the traditional consultation model. Edited and adapted from Kidd et al. (2011).

The conceptual framework for the involvement of patients within the decision-making process has been extensively reviewed (Entwistle and Watt, 2006). However, as reported by Dierck et al., (2013), physiotherapists often do not incorporate patient preferences or values within their decision-making process, or even allow patients to provide their opinions about the proposed treatment plan. It can be argued, however, that the inclusion of patient needs and preferences within the decision-making process may not always be suitable and clinically inappropriate (de Haes, 2006). Therefore, the inability of a patient to participate fully in their own rehabilitation programme of care since they are unable to effectively contribute, and the fact that their needs and preferences are not considered because they are clinically inappropriate, can subsequently influence the level of patient-centeredness within the patient-clinician relationship, as patients themselves are unable to participate in their own care (Leach, Cornwell, Fleming, and Haines, 2010). Now, if patient views and preferences are not integrated within the decision-making process about treatments interventions, they may be less likely to adhere to their rehabilitation programme, which may result in reduced motivation, cooperation and dissatisfaction that may ultimately prevent patients from achieving optimal recovery (Bowling and Rowe, 2005; Brindis and Sennett, 2003).

In the limited empirical research to date, the concept of patient-centred care remains a complex interaction and a contested issue requiring additional research (Mead and Bower, 2000; Gillespie et al., 2004). Within the specific field of physiotherapy, it remains unclear precisely what is meant or understood by the term 'Patient-Centred Care' and how this can be implemented effectively in clinical practice (Cooper et al., 2008). Arguably, a more detailed understanding of patient preferences for treatment is necessary in order to achieve an effective shared clinical decision, and to allow the patient and the physiotherapist to set realistic and desired rehabilitation goals (Schoeb et al., 2014).

Within the specific field of orthopaedic physiotherapy, limited empirical research has yet to investigate how the process of goal-setting can be effectively achieved, and how this process of goal-setting between a patient and physiotherapist may affect a patient-centred approach (Schoeb, 2009). In summary, it has been suggested that a patient's involvement in goal-setting and the shared decision-making process, should improve patient satisfaction, adherence to rehabilitation, and health outcomes. In this respect, this concept would appear to be a prerequisite for good clinical practice even though the current evidence remains limited (Dierck, Deveugele, Roosen et al., 2013). The literature regarding patient preference for different treatment options, where alternatives exist, is sparse and the concept requires further investigation (Bowling and Ebrahim, 2001; Brindis and Sennett, 2003).

The delivery of physiotherapeutic treatment strategies varies substantially within physiotherapy practice, and this has been used to explain the reasons for discrepancies in healthcare outcomes (Lutfey et al., 2008). Physiotherapists have access to a multitude of manual therapies and modalities which need to be applied using a problem-solving approach. A single treatment intervention is rarely, if ever, implemented (Langendoen, 2004; Shiell, Hawe, and Gold, 2008). More often, a structured rehabilitation programme will be developed, which follows a standardised approach that is subsequently individualised to each patient's needs and is, generally, an evidence-based and milestone-driven protocol (Heijne, Axelsson, Werner, and Biguet, 2008)[1]. A continuing challenge for physiotherapists is to devise the most rapid, effective and individualised recovery process to restore patients to their pre-injury status (Langendoen, 2004). During this rehabilitation process it is important that physiotherapists assess and quantify a patient's progress over time. These measurement tools are labelled as 'outcome measures' (Irrgang and Lubowitz, 2008).

Outcome measures are, generally, divided into two broad categories as either Patient-Based Outcome Measures - this method of self-report, taking the acronym, P-BOMs, also known as Patient-Rated Outcomes (PRO), will be used throughout this thesis. Clinician-Based Outcome Measures (C-BOMs), also known as Clinician-Rated Outcomes (C-RO), are often referred to as 'subjective' and 'objective' outcome measures, respectively (Bent, Wright, Rushton, and Batt, 2009; Synder et al., 2008). C-BOMs (objective measurements) are considered to generate more robust and clinically meaningful information and, quite often, involve a higher level of collected data (such as ratio, interval, and ordinal data). In contrast, 'subjective' patient-based assessments usually involve a patient completing a questionnaire or inventory-based assessment (Poolman et al.,

[1] An example of a post-operative ACLR rehabilitation protocol used within the physiotherapy practice (Robert Jones and Agnes Hunt Orthopaedic Hospital [RJAH], Oswestry, UK) can be seen in **APPENDIX 1** (p. 440).

2009)[2]. A P-BOM refers to an array of self-report measures, interview schedules, and other related methods of assessing health, illness and benefits of health care interventions from the patient's perspective (Collins, Misra, Felson, Crossley, and Roos, 2011; Fitzpatrick, Davey, Buxton, and Jones, 1998). Therefore, P-BOMs subjectively assess an individual's perceived dysfunction or disability following injury, disease or illness (Reiman and Manske, 2011)[3].

Along with the use of P-BOMs, C-BOMs can also include a number of different methods to measure functional and physical ability, but from the perspective of the clinician (Suk, Hanson, Norvell, and Helfet, 2005). C-BOMs usually take the form of an objective measurement or test performed either by the clinician themselves (i.e., physiotherapist measuring range of motion using goniometry of the knee joint, or performing a Lachman test for measuring anterior cruciate ligament integrity), or by the patient performing a functional or performance-based test; for example, a Single-Leg Hop for distance test measured for time or distance (Gulick and Yoder, 2002; Reid, Birmingham, Stratford, Alcock, and Giffin, 2007). Generally, these C-BOMs objectively tests a patient's ability in a specific task that is evaluated in a standardised manner using predetermined criteria, such as counting repetitions performed, or the time it takes to complete a task (Guralnik, Branch, Cummings, and Curb, 1989). Clinician observation of such functional-based tests provides an opportunity for clinicians to assess functional activity and subsequently make an informed decision regarding the patient's progress in their performance (Binkley, 1999). Clinician-based measurements generally assess the functional impairment related to the injury, disease or illness (Reiman and Manske, 2011).

With both P-BOMs and C-BOMs used in clinical practice, it has been suggested that both should be deployed equally to obtain a truly 'global' assessment of a patient-perceived disability and associated physical impairments (Howe, Dawson, Syme, Duncan, and Reid, 2012). However, the current literature seems to suggest that physiotherapists do not routinely incorporate P-BOMs within their current physiotherapy practice (Copeland, Taylor, and Dean, 2008; Jette, Halbert, Iverson, Miceli, and Shah, 2009; Swinkels, Van-Peppen, Wittink, Custlers, and Beurskens, 2011). Several reasons for this have been proposed, with some physiotherapists reporting that P-BOMs are, at times, unpractical and unfeasible within the rehabilitative setting and, quite often, P-BOMs are complex and too time-consuming to administer and evaluate within a defined consultation

[2] For the purpose of this thesis, the terms 'subjective' and 'objective' outcome measures will not be used, as the term 'subjective' may have a negative connotation if misinterpreted as an antonym to the term 'objective' (Irrang and Lubowitz, 2008).

[3] In accordance with a P-BOM definition, which is defined as any outcome measure that is directly assessed from the patient's perspective on any health status without the interpretation of the patient's response by a clinician (Deshpande et al., 2011); this measure of subjective/self-report from a patient's perspective (which is not directly interpreted by a clinician) will be referred to as an 'assessment outcome measure' only. Therefore, overall the term Patient-Based Outcome Measure (P-BOM) is the preferred term to 'subjective' which encompasses any method of 'self-report' undertaken by an individual at the time of completion.

period (Phillips, Benjamin, Everett, and Van Deursen, 2000; Hammond, 2000). Furthermore, many physiotherapists have reported that they lack the appropriate information and thus confidence in selecting appropriate P-BOMs within their practice (Bent, Wright, Rushton, and Batt, 2009). To further complicate this, only a few P-BOMs, for example within an Anterior Cruciate Ligament (ACL) Reconstruction (ACLR), have demonstrated satisfactory levels of reliability, validity, and responsiveness; therefore, selecting a suitable P-BOM can be challenging for clinicians (Dalton, Davidson, and Keating, 2012; Davidson and Keating, 2014).

It has been reported that patients own functional status, Quality of Life (QoL) and satisfaction can be more precisely reported by the patients themselves rather than by the clinician (Lloyd, Jenkinson, Hadi, Gibbons, and Fitzpatrick, 2014). This has led to the development of a considerable number of different P-BOMs, questionnaires and other rating scales to measure the patient's perspective (Wang, Jones, Khair, and Miniaci, 2010; Garrat, Brealey, and Gillespie, 2004). Recent systematic reviews have examined the types of P-BOMs used to assess knee function, and the psychometric evidence for each P-BOM has been identified (Wang et al., 2010; Collins et al., 2011). Only P-BOMs that are commonly used and have demonstrated valid and reliable psychometric properties were included in both reviews **(**see **TABLE 1)**.

TABLE 1 - Recommended P-BOMs for different knee pathology and assessment parameters. Edited and adapted from: Wang et al. (2010)[1] and Collins et al. (2011)[2].

ASSESSMENT PARAMETER	**RECOMMENDED P-BOM(S)**
ACLD/ACLR	IKDC[2], Cincinnati[1], KOOS[1,2], Lysholm[1]
Anterior knee pain	Kujala[1]
Focal chondral injury	IKDC[1,2], KOOS[1,2], Lysholm[1]
Meniscal injury	IKDC[2], KOOS[2], WOMET[1], KOS-ADL[2]
Patellofemoral pain	KOS-ADL[2], IKDC[2]
OA	KOOS[1,2], OXFORD[1], KOS-ADL[2], WOMAC[2]
General	IKDC[1,2], KOOS[1]
TKA[4]	KOOS[1,2], OXFORD[1]
Sport-specific activity	TAS[1], ARS[2]
Functional activity	MARX[1]

[4] Total Knee Arthroplasty (TKA).

Within the field of rehabilitation, clinicians and researchers have a common vocabulary and language for thinking and speaking about the disablement process (Jette, 2006). Verbrugge and Jette (1994) described this disablement process as **(1 :)** how medical conditions affect functioning in particular body systems, physical and mental actions, and daily activities, and **(2 :)** how personal and environmental factors can exacerbate or delay the disablement process (Sullivan and Cen, 2011). Several disablement models (Nagi Disablement Model [Nagi Model], National Centre for Medical Rehabilitation Research Disablement Model [NCMMR], and The International Classification of Functioning, Disability and Health [ICF])[5] have now been introduced, which allow healthcare professionals to communicate with one another and to speak in a common language across related professional disciplines, regarding patients' overall health status (Jette, 2009)[6]. In general, disablement models are conceptual schemes or scientific models that form the basic architecture for clinical practice and research, as well as healthcare policy (Kaplan, 2007).

The use of disablement models provides a foundation for defining the clinical outcome measures to be used in clinical practice, which will enable an understanding of a patients' overall health status (Snyder et al., 2008). In this context, disablement models serve as a framework by which clinical outcome assessments can be used to examine the effectiveness of healthcare services or interventions based upon one or more dimensions of disablement (Valovich McLeod, Bay, Parsons, Sauers, and Snyder, 2008). Furthermore, P-BOMs may be incorporated into a treatment plan to supplement C-BOMs. Such an approach allows a more complete assessment of a patient's perception of their own health status. In this regard, P-BOMs should always be included within patient consultations to further elucidate and understand what is important to the patient (Michener, 2011). At present it remains unknown what outcome measures (P-BOM or C-BOM) are necessary to effectively deliver a truly 'global' assessment of a patient following ACL injury (Howe et al., 2012).

In the description and classification relating to Anterior Cruciate Ligament (ACL) injury, the International Classification of Functioning, Disability and Health (ICF) model (WHO, 2016) has been used as a common framework by healthcare professionals in understanding the overall health status of patients (Snyder et al., 2008; Logerstedt, Snyder-Mackler, Ritter, Axe, and Godges, 2010). Within this model, various components or domains (**[1 :]** Body Structure and Functions, and

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[5] The International Classification of Functioning, Disability and Health Model, known more commonly as ICF model, is a classification of health and health-related domains. ICF is a WHO framework for measuring health and disability at both individual and population levels (WHO, 2016). For the purpose of this thesis, the ICF will be referred to as either, ICF, ICF model, and/or ICF framework. For a comprehensive review of the ICF framework refer to Michener, 2011.

[6] Consult Logerstedt et al. (2010) for a comprehensive guide to the ICF disablement model which classifies and defines common musculoskeletal conditions using the World Health Organization's terminology related to Impairments of Body Function and Body Structure, Activity Limitations, and Participation Restrictions, whilst also identifying appropriate outcome measures that can be deployed to evaluate outcome.

[2 :] ‘Activity and Participation’) are used to classify injury, and these domains are necessary to comprehensively assess the impact of ACL injury on a person’s overall well-being **(**see **FIGURE 2**; p. 44**)**.

Michener (2011) comprehensively evaluated the importance of P-BOMs and C-BOMs in assessing patient outcomes and the use of these assessment methods to guide therapeutic care decisions, in particular, the use of outcome measures from the ICF framework. Therefore, P-BOMs and C-BOMs are directly examining different components of a patient’s injury from the perspective of the clinician and the patient’s assessments, disability and impairment, respectively. Principally, the ICF domains within the ICF model consist of the following: **(1 :)** Body Structure and Function and **(2 :)** Activity (limitation) and Participation (restriction) domains **(FIGURE 2**; p. 44**)**[7].

It should be noted that the well-established C-BOMs (for example the Anterior Draw test [measuring physical impairment] as defined within the ICF framework from the Body Structure and Function domain) does not take into account or indeed reflect potential difficulties patients have in performing more functional activities associated with normal daily life. Hence, the importance of evaluating outcome from the Activity Limitation and Participation Restriction domain.

Within the Activity and Participation domain, both P-BOMs and C-BOMs can be deployed to evaluate injury. For example, within this domain, common methods of evaluating lower extremity function with ACLD and ACLR patients are via functional performance outcomes (C-BOMs). Here, a Single-Leg Hop for distance test for distance is a common practical, performance-based outcome that is inexpensive to administer that reflects the integrated effect of neuromuscular control, strength, and confidence in the limb (Reid et al., 2007). Other Activity Limitation and Participation Restriction outcome measures form part of the ICF model (examples provided in **FIGURE 2**; p. 44) which are designed to capture the patient’s perspective of their injury (Logerstedt et al., 2010.

Reliable, validated and responsive standardised outcome measures used in research (Swiontkowski, Buckwalter, Keller, and Haralson, 1999) and clinical practice (Marshall, Haywood, and Fitzpatrick, 2006) have been repeatedly described in the orthopaedic literature as important (Poolman et al., 2009) to monitoring progress and facilitating clinical decision-making during the rehabilitation process following surgery or injury (Bradbury, Brosky, Walker, and West, 2013; Reid et al., 2007; Irrgang and Lubowitz, 2008).

[7] Consult Logerstedt et al. (2010) for a comprehensive guide to the ICF disablement model which classifies and defines common musculoskeletal conditions using the World Health Organization’s terminology related to impairments of body function and body structure, activity limitations, and participation restrictions, whilst also identifying appropriate outcome measures that can be deployed to evaluate outcome.

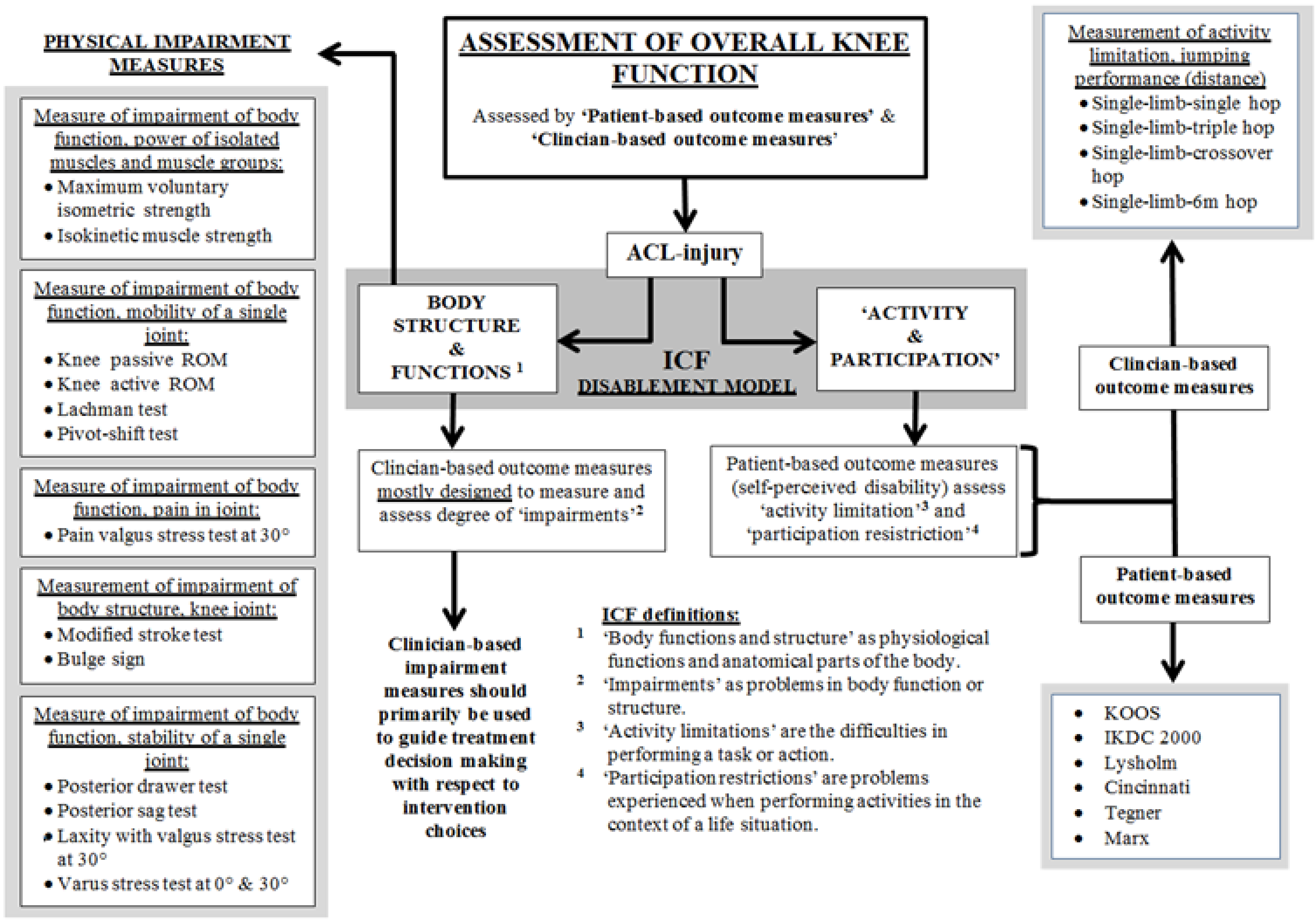

FIGURE 2 - International Classification of Functioning, Disability and Health by the World Health Organization (WHO, 2016), edited and adapted from Michener (2011) and Snyder et al. (2010).

Considering the large number of P-BOMs (Wang et al., 2010; Garratt, Brealey, Gillespie, and Team, 2004) and clinician-applied outcomes (Narducci, Waltz, Gorski, Leppla, and Donaldson, 2011) currently deployed in clinical practice by clinicians and researchers to assess patients' outcomes, a recurring challenge is that there has only been a low-to-moderate correlation between the results of these P-BOMs and C-BOMs, following different types of knee pathologies and surgeries (Chmielewski et al., 2011; Gandhi, Tsvetkov, Davey, Syed, and Mahomed, 2008; Coman, and Richardson, 2006; Maly, Costigan, and Olney, 2006; Kennedy, Stratford, Pagura, Walsh, and Woodhouse, 2002). Attempts have been made to try to examine whether relationships exist between P-BOM and C-BOM outcomes when both forms of assessment are administered concomitantly (Gokeler et al., 2012; Clarke, 2001; Fitzgerald, Lephart, Hwang, and Wainner, 2001; Pua, Bryant, Steele, Newton, and Wrigley, 2008). Moreover, only three reviews have been conducted to examine relationships between P-BOM and C-BOM outcomes in ACLD and ACLR patients following ACL injury and post-ACLR surgery (Gokeler et al., 2012; Fitzgerald et al., 2001; Pua et al., 2008).

Within the first review, Fitzgerald et al., (2001) identified only four studies (Noyes, Barber, and Mangine, 1991; Wilk, Romaniello, Soscia, Arrigo, and Andrews, 1994; Borsa, Lephart, and Irrgang, 1998; Sernert et al., 1999), which investigated the functional hop test as a physical performance measure for ACLD and ACLR patients following ACL injury and surgery (Fitzgerald et al., 2001). Within this clinical commentary, the relationships between routinely-deployed outcome measures of muscle performance, knee laxity, knee joint position sense, functional hop test and patient-based measurements were compared to understand whether these P-BOMs and C-BOMs could provide predictors of dynamic knee stability.

The results showed the correlation coefficients identified either negligible or no relationships, with low correlations overall for reported values between all P-BOMs with functional hop tests ranging from $r = 0.11$ to 0.48 [Noyes et al., (1991), $r = 0.03$ to 0.28 ($n = 67$); Wilk et al., (1994), $r = 0.31$ to 0.48 ($n = 50$); Borsa et al., (1998), $r = 0.11$ to 0.28 ($n = 29$); and Sernert et al., (1999), $r = 0.28$ to 0.36 ($n = 527$)]. The highest correlation coefficient ($r = 0.48$) was reported for the total score of the Cincinnati (P-BOM) with the Single-Leg Hop for distance (a C-BOM). Fitzgerald and colleagues (2001), in summary, reported that the low correlation coefficients reported between functional hop tests (C-BOM) and the P-BOM methods of function may indicate that neither functional hop tests nor P-BOMs can stand alone as an adequate assessment of knee function, and each of these assessment methods may capture different aspects of physical performance and function. Indeed, both types of outcome measure may be needed to describe the patient's status of function, impairment, and disability at a given point in time. Furthermore, the functional hop test procedures might potentially predict dynamic knee joint stability; however, the authors suggested that more research in this area is still required.

Secondly, Pau and colleagues (2008) presented a narrative review of six studies (Harter et al., 1988; Wilk et al., 1994; Seto, Orofino, Morrissey, Medeiros, and Mason, 1988; Holm, Risberg, Aune, Tjomsland, and Steen, 2000; Ross, Irrgang, Denegar, McCloy, and Unangst, 2002, and Bryant, Kelly, and Mohmann, 2008) examining the association between measurements of dynamometry examining various isokinetic muscle strength performance variables (i.e., Peak Torque (PT), Total Work (TW), and various angular knee velocities ranging from 60-450°/s) for the knee flexors and extensors (C-BOM) with P-BOMs of knee function in ACLR patients (Cincinnati, Knee Outcome Survey, Sports Activity Scale and Activities of Daily Living Scale, Knee Function Rating Form, and Functional Activity Questionnaire). The correlation coefficients between the various isokinetic quadriceps and hamstring variables and P-BOMs ranged from, approximately, r = 0.13 to 0.79 for the knee extensors, and r = 0.17 to 0.80 for the knee flexors [Harter et al., (1988), r = value not report (n = 51); Wilk et al., (1994), r = 0.13 to 0.71; Seto et al., (1988), r = 0.74 to 0.80 (n = 25); Holm et al., (2000), r = 0.17 to 0.39 (n = 151); Ross et al., (2002), r = 0.29 (n = 50); and Bryant et al., (2008a), r = 0.40 to 0.59 (n = 13)]. The authors noted that given the multifactorial nature of injured athletes' activity levels or performance statuses, it would be unreasonable to expect isokinetic measures from a single muscle group to have a strong relationship with the patient-reported outcome measures (Pua et al., 2008).

Thirdly, a more recent Systematic Review examined the relationship between two commonly-used proprioceptive tests (Joint Position Sense [JPS] and Threshold to Detect Passive Motion [TTDPM]) with muscle performance variables, knee laxity, balance tests, functional hop tests and P-BOMs (KOOS[8], Tegner Activity Scale (Tegner), Cincinnati Knee Rating Scale (Cincinnati) and Lysholm Knee Rating (Lysholm), Visual Analogue Score (VAS) for subjective knee rating, patient satisfaction, and performance rating questionnaires). The aim of this review was to examine the clinical relevance of proprioceptive deficits reported after ACL injury in both ACLD and ACLR patients (Gokeler et al., 2012). The systematic review identified 24 studies. Overall, low to moderate correlations were found between proprioceptive tests (JPS and TTDPM) and strength performance, balance, functional-hop tests and P-BOMs for ACLD and ACLR patients.

It is relevant here that 15 studies assessed the relationship between proprioceptive tests (JPS and TTDPM) and P-BOMs (KOOS, Tegner, Cincinnati, Lysholm, VAS, patient satisfaction, and performance rating questionnaires). In four of these studies, there was either no correlation or only low correlations reported between proprioceptive tests and the KOOS or the Cincinnati (Borsa et al., 1998; Risberg, Beynnon, Peura, and Uh, 1999; Wright, Tearse, Brand, and Gabel, 1995; Ageberg and Fridén, 2008). In two of the three studies where the two proprioceptive tests were compared with the Lysholm, no correlations were found (r = -0.19, p= nr[9]) (Borsa et al., 1998;

[8] Knee injury and Osteoarthritis Outcome Score (KOOS).
[9] Not reported.

Reider et al., 2003), but in the other remaining study, a positive moderate correlation was found (r = 0.60) (Fischer-Rasmussen and Jensen, 2000). In three of the studies which compared the two proprioceptive tests with Tegner, no correlations were found (r = -0.18 to -0.36 and p values ranging from 0.03 to 0.08) (Ageberg, Roberts, Holmström, and Friden, 2005; Roberts, Andersson, and Fridén, 2004; Ageberg and Fridén, 2008). In four studies, in which the two proprioceptive tests were compared with VAS subjective knee rating scores, low correlations were, again, reported (Fridèn et al., 1999; Roberts et al., 2007; Ageberg et al., 2005; Roberts et al., 2004). In three studies, the relationship between the two proprioceptive tests and patient satisfaction or performance rating questionnaires were assessed, however, no correlations were found (Fischer-Rasmussen and Jensen, 2000; MacDonald, Hedden, Pacin, and Sutherland, 1996; Fremerey, Lobenhoffer, Born, Tscherne, and Bosch, 1998).

Finally, in the remaining study, the relationship between two proprioceptive tests and Cincinnati and IKDC was assessed on two occasions unlike the other studies which assessed the relationship on only one occasion. At 3 months’ post-surgery, a correlation coefficient value of r = 0.63 (p = 0.021) suggested a moderate positive correlation between the proprioceptive tests and Cincinnati. However, at 6 months’ post-surgery, a lower correlational coefficient value was reported (r = 0.22, p = 0.44). In contrast, the relationship effect was different for the IKDC, where there was no correlation found at 3 months’ post-surgery (r = 0.23, p = 0.408), however, at 6 months' post-surgery a low positive correlation was reported (r = 0.44, p = 0.807). Therefore, the correlation between proprioception and P-BOMs cannot be judged with confidence. This review represents the first attempt to systematically address the relationship between P-BOMs evaluated concomitantly within C-BOMs using proprioceptive methods of assessment. The authors reported that correlations between P-BOMs and the two proprioceptive tests, in general, were not evident (Gokeler et al., 2012).

The recurring themes that emerge from these three reviews is that there appears to be an inconsistent lack of correlations which are statistically and clinically relevant, amongst P-BOMs and C-BOMs, further endorsing the quandaries that challenge clinicians and researchers. Given the relatively low number of studies evaluated in each review, the heterogeneity of the P-BOMs and C-BOMs which were mostly non-comparable, with no same P-BOMs being consistently evaluated with the same C-BOMs, the strength of the relationships remains relatively speculative, warranting further investigation. Unfortunately, at this time, these reviews do not provide sufficient justification for the single use of one P-BOM and/or C-BOM across any stage of ACL rehabilitation. Further, the relationships reported vary substantially across a wide time frame of up to 5 years post-ACL injury or 5 years post-ACLR surgery, making the relationships difficult to interpret.

Furthermore, the issues of the minimum number of either P-BOMs or C-BOMs that might be needed to properly describe changes in functional or physical performance of patients during their rehabilitation, and importantly, whether P-BOMs or C-BOMs offer most validity (Reiman and Manske, 2011), remain unknown. More specifically, a low correlation suggests that each outcome is assessing a different component of capability (that shares no variance with other relevant outcomes). Given the clear lack of understanding over which outcome measure (P-BOM or C-BOM) should be deployed in clinical practice, the current literature suggests that researchers and clinicians must gain a comprehensive representation of patients using as many P-BOMs and C-BOMs as possible.

Further empirical research has been conducted to perform correlational investigations, whose primary aim was to assess the relationships between P-BOMs and C-BOMs in ACLD and ACLR patients (Ross et al., 2002; Kocher, Steadman, Briggs, Sterett, and Hawkins, 2004; Bryant, et al., 2008b; Bryant et al., 2008a; Park et al., 2010; Trulsson, Roos, Ageberg, and Garwicz, 2010; Reinke et al., 2011; Baltaci, Yilmaz, and Atay, 2012; Kong et al., 2012). However, these studies reported great inconsistency in the correlation coefficients similar to the three reviews discussed above. The reasons for the differences in relationship values is difficult to interpret, and therefore requires speculation on an individual basis (Pua et al., 2008). Indeed, inconsistencies may be due to differences in subject population and pathologic condition or differences in the non-standardised approaches used in the methodological testing of patients, combined with various types of equipment used for testing patient outcomes' (i.e., dynamometry) and the different methods of assessing the test results (Wilk et al., 1994).

Several more explanations have been proposed for this lack of relationship between P-BOMs and C-BOMs; one explanation suggests this is due to the fact that each P-BOM and C-BOM quantifies different aspects of function and recovery (Akker-Scheek, Zijlstra, Groothoff, Bulstra, and Martin, 2008; Reid et al., 2007; Stratford and Kennedy, 2006; Fitzgerald et al., 2001). For example, a P-BOM will examine a patient-perceived dysfunction and disability, whilst a C-BOM, including clinical tests, will measure specific levels of impairment (Neeb, Aufdemkampe, Wagener, and Mastenbroek, 1997). Another explanation for the inconsistencies in correlation coefficients may be associated with measurement error, the extent to which P-BOMs adequately encompass what they say they are measuring, and the relationship between C-BOMs and the accurate physical demands associated with Activities of Daily Living (ADL) (Hoeymans, Feskens, Van Den Bos, and Kromhout, 1996; Rejeski, Ettinger, Shumaker, Burns, and Elam, 1995).

Similarly, correlational investigations assessing the relationship, or content validity, between different types of P-BOMs (i.e., IKDC versus KOOS) have also reported poor correlations (Anderson, Federspiel, and Snyder, 1993) and these comparison studies are often described as inappropriate (Hrubesch et al., 2000) because poor correlations may be due to the fact that different P-BOMs place emphasis and weighting on different aspects of subjective and objective knee function when generating scores (Shaw, Chipchase, and Williams, 2005). Given the poor relationships reported in correlational studies directly assessing relationships between P-BOMs themselves (i.e., IKDC versus KOOS), and the poor to moderate correlations found when assessing P-BOMs and C-BOMs concomitantly, not to mention the lack of possible explanations for these poor relationships (Akker-Scheek et al., 2008), further investigations to gain greater understanding of these relationships following ACL injury and rehabilitation are still required to determine their potential implications for future practice (Chmielewski et al., 2011; Reiman and Manske, 2011).

When determining the suitability of a clinical outcome measure it is important that both the P-BOMs and C-BOMs strongly correlate with the level of disability experienced by the patients (Irrgang, Safran, and Fu, 1996; Keller, Rudicel, and Liang, 1993). However, as previously mentioned the current literature reports poor correlations for these interactions, owing mainly to the fact that each patient- and clinician-based method of assessment quantifies different aspects of function and recovery that cannot be causally linked (Akker-Scheek et al., 2008). As such, it may not be effective to use one method of assessment over another, and both P-BOMs and C-BOMs may need to be used to complete the patient assessment (Shaw et al., 2005).

A P-BOM known as Performance Profile (Butler and Hardy, 1992) has recently been investigated in two correlational studies (Gleeson, Parfitt, Minshull, Bailey, and Rees, 2008; Yates, Alkitani, Darain, Bailey, and Gleeson, 2016)[10] to assess how an injured patient construes his or her own rehabilitation and recovery following ACL injury (Doyle, Gleeson, and Rees, 1998), with an evaluation of the correlations between the Performance Profile and other P-BOMs (i.e., IKDC[11], Emotional Responses of Athletes to Injury Questionnaire [ERAIQ], Bipolar Profile of Mood States [Bi-POMs]) versus a range of neuromuscular outcome measures (C-BOMs: Peak Force (PF: knee flexor strength), Electromechanical Delay (EMD: time lag between the onset of electrical activity and tension development in human muscle), Anterior Tibio-Femoral Displacement (ATFD: evaluation of knee ligamentous compliance [knee laxity]), over time, evaluated at pre-surgery and at 8 and 10 weeks post-ACLR surgery.

An emotional Performance Profile was elicited based on the individualised emotional responses experienced (i.e., confident, worried, depressed, etc.) by injured athletes post-ACL injury (Gleeson et al., 2008), where the Performance Profile was significantly ($p< 0.01 - 0.05$) and highly correlated (Hinkle, Wiersma, and Jurs, 2003) with C-BOMs (PF [$r_s = 0.82$ to 0.85], EMD [$r_s = 0.81$ to 0.84], and ATFD [$r_s = 0.68$ to 0.72] over time evaluated at pre-surgery and at 8 and 10 weeks post-ACLR surgery.

The Performance Profile emotional disturbance scores decreased post-ACLR surgery, with less emotional discrepancy (10 weeks post-ACLR surgery versus pre-ACLR surgery, 6, 8 weeks

[10] Unpublished research and under review.
[11] The International Knee Documentation Committee (IKDC) Subjective Knee Form.

post-ACLR surgery). A higher Performance Profile emotional disturbance score was significantly ($p< 0.05$) correlated to higher ATFD scores (2, 8, and 10 weeks post-ACLR surgery) (rs = 0.68, 0.72, 0.70, respectively). ATFD being a key marker of knee joint stability and ACL performance following ACLR (Gleeson, 2001). Other significant correlations ($p< 0.01$) were observed between emotional Performance Profile scores and PF and EMD at 8 weeks (rs = 0.85, -0.81) and 10 weeks (rs = -0.82, -0.84) post-ACLR surgery, with a higher Performance Profiling emotional disturbance score correlating with muscular weakness (PF) and longer muscle-activation delays (EMD) (pre-surgery, 8, 10 weeks post-ACLR surgery). These neuromuscular outcome measures: PF and EMD, help determine the level of joint system stability (Minshull, Gleeson, Walter-Edwards, Eston, and Rees, 2007).

In summary, the strength and patterning of the correlations over the testing occasions between emotional Performance Profile and C-BOMs (PF, EMD, and ATFD) over time demonstrate their validity as a psychophysiological assessment tool (Gleeson et al., 2008). The strength of these relationships (explaining up to 82% of shared C-BOM and P-BOM variance) suggest that the Performance Profile could be a viable alternative to the P-BOMs traditionally used within ACL assessments. For example, the Bi-POMs and the ERAIQ responses had inconsistent patterns of response (in comparison to Performance Profile) and relationships on all four assessment occasions. As expected, and contrary to the current literature (Risberg, Holm, Steen, and Beynnon, 1999; Shelbourne, Barnes, and Gray, 2012) the IKDC did not report any significant relationships for this P-BOM, which is commonly used to assess ACL outcomes (Christensen et al., 2015).

Further research (Yates et al., 2016) investigated whether the Performance Profile incorporating physical responses (i.e., pain, strength, instability, etc.) versus previously identified emotional responses to ACL injury over the same assessment period would correlate to concomitant changes in C-BOMs. In addition to investigated neuromuscular outcome measures (PF, EMD) of knee flexors (Gleeson et al., 2008), neuromuscular performance outcomes with the knee extensors (primary dynamic stabiliser of the knee joint) were also evaluated by Rate of Force Development (RFD: the ability to exert high muscle force in a timely manner) (Minshull et al., 2012) which has been considered a marker for returning to sport (Knezevic et al., 2014), and could act as a meaningful comparator of Performance Profile responses. Interestingly, authors also evaluated Sensorimotor Performance (SMP: ability to scale volitional force precisely and measured as the Force Error (FE) (Gleeson, 2001)) in addition to P-BOMs and C-BOMs, previously evaluated over the same four assessment occasions (pre-surgery, 2, 6, and 10 weeks post-ACLR surgery). Only Sensorimotor Performance has been causally linked with ACL injury versus other neuromuscular performance outcomes (PF, EMD, and RFD) (Hewett et. al, 2006; Griffin et al., 2006), contrasting with a more recent systematic review (Gokeler et al., 2012) that evaluated Sensorimotor Performance against a range of C-BOMs. More interestingly, no relationships were found concurrently between the commonly-used P-BOMs and Sensorimotor Performance outcomes, therefore this warrants further investigation.

Interestingly, there were no statistically significant ($p < 0.05$) correlations amongst C-BOMs (ATFD, PF, EMD, RFD, and Sensorimotor Performance (SMP-FE) associated with Force Error (FE) and P-BOMs (Performance Profile and IKDC) at any assessment occasion (2 weeks pre-ACLR surgery, and 6, 8 and 10 weeks post-ACLR surgery). However, the Performance Profile discrepancy scores at 10 weeks post-ACLR surgery correlated significantly with C-BOM scores from 8 weeks post-ACLR surgery (ATFD [$r_s = 0.68$; $p < 0.05$]; PF [$r_s = 0.71$; $p < 0.05$]; EMD [$r_s = 0.80$; $p < 0.01$]; RFD [$r_s = 0.71$; $p < 0.05$]; SMP-FE [$r_s = 0.70$; $p < 0.05$]). Similarly, significant relationships were found between Performance Profile discrepancy scores at 8 weeks post-ACLR surgery and C-BOMs at 6 weeks post-ACLR surgery (ATFD [$r_s = 0.70$; $p < 0.05$]; PF [$r_s = 0.70$; $p < 0.05$]; EMD [$r_s = 0.74$; $p < 0.01$); RFD [$r_s = 0.69$; $p < 0.05$); SMP-FE ($r_s = 0.68$; $p < 0.05$]). This finding suggested that an assessment latency of 2 weeks (objective clinician-reported performance outcome measures preceding the subjective patient-perceived perception of capability) elicited significant relationships amongst selected P-BOMs (Performance Profile) and C-BOMs (PF, EMD, RFD, and SMP-FE), offering moderate clinical relevance.

Ideally, the outcome of this latter study should have shown that P-BOMs and C-BOMs offer a shared pattern of congruency and responsiveness such that patient perceptions of changes in their capability might properly reflect and mimic physicality during all stages of rehabilitation. Nevertheless, in contrast to the positive direction of the physical performance changes described by C-BOMs, the P-BOMs of Performance Profile (but not IKDC), which had been unresponsive - contrasting with previous literature (Christensen, Goldfine, Barker, and Collingridge, 2015) - had identified that greater dysfunction and impaired fitness was perceived by participants in their injured knee at 6 weeks post-ACLR surgery compared to pre-surgery. It is therefore important for clinicians to be aware that participants are likely to considerably miscalibrate their true capabilities and to perceive high levels of dysfunction during this initial period of rehabilitation. As such, it would seem useful to provide any evidence of concomitant physical improvements occurring from pre-surgery levels to patients as feedback in order to reassure them of their progress towards favourable clinical outcomes (Gleeson et al., 2008). Moreover, the presented studies demonstrate the efficacy of Performance Profiling as an assessment tool within a clinical setting (Doyle et al., 1998).

As with all research, there were limitations to both of these profiling studies which should be considered when interpreting the results and conducting future research. Further research might examine the pre-operative levels of physical function in ACL patients, using a larger sample size, and examining age-related differences in patients. Moreover, the heterogeneity of the number of rehabilitative sessions and the number of minutes performing the exercise therapy might also call the validity of the results into question. It would therefore also be necessary to assess patients with a reduced waiting time from injury to ACLR surgery and to control the rehabilitation performed, to determine whether anthropometric- and orthopaedic-related factors influence correlational outcomes (Holla et al., 2013; Vincent, Vincent, Lee, and Alfano, 2006; Lohmander, Ostenberg, Endlund, and Roos, 2004).

In defining the Performance Profile, Butler and Hardy (1992) were originally dissatisfied with the traditional dictated nature of athletes' coaches and their sport-psychology consultancy approaches, which encouraged little involvement by the athlete in the decision-making process during the initial performance assessment phase in preparation for elite competitive events. Consequently, important information and knowledge from the athlete's perspective may have been missed (Butler, Jones and Irwin, 1993; Weston, Greenlees, and Thelwell, 2013). Furthermore, authors reasoned that in this scenario where athletes' perceived needs and perceptions are not understood and the devised training programme did not meet their expectations, then the athlete's motivation towards it would be decreased (Weston, Greenlees, and Thelwell, 2011b). Therefore, Butler and Hardy (1992) developed a client-centred, idiographic profiling tool and strategy to assess performance and examine how an athletic-performer construes his or her own performance in preparation for competition (Weston et al., 2013), all of which, was designed to incorporate and encourage the athlete within a shared decision-making process, encouraging communication between the athlete and their management team to circumvent traditional consultancy approaches (Butler and Hardy, 1992; Butler et al., 1993; Dale and Wrisberg, 1996).

Fundamentally, the Performance Profile is described as an athlete-, patient-specific or is similarly described as an individualised outcome measure (Butler and Hardy, 1992; Doyle et al., 1998; Horn, Jennings, Richardson, Vliet, Hefford, and Abbott, 2012). In the latter, individualised outcome measures refer to assessments and outcome measures in which the problem areas perceived are measured specifically for each individual patient's needs and this can be established by either the patient or the clinician at the time of construction (Khorsan, Coulter, Hawk, and Choate, 2008). For example, patients are able to construct an individualised outcome measure by selecting his or her own issues, domains or concerns regarding which outcomes have personally been affected since the time of injury (Fitzpatrick et al., 1998). This assessment method is not therefore defined based on a set of predetermined questions and standardised list of potential answers is imposed (Fitzpatrick et al., 1998; Ruta and Garratt, 1994). To date, no comprehensive review or systematic evaluation of individualised outcomes has yet been published for ACL-related outcomes.

Recent reviews, moreover, (Doyle et al., 1998; Gucciardi and Gordon, 2009b; Weston et al., 2013) have all suggested the widespread popularity and potential benefits and usefulness of using individualised outcome measures such as the Performance Profile with athletes, to enhance their athletic performance. Nonetheless, the surrounding empirical evidence remains somewhat deficient (Weston, Greenlees, and Thelwell, 2010) and a large majority of the published literature underpinning the use of this profiling technique is seemingly inadequate. For example, some studies are primarily based on descriptive reflections within single case study designs, or include relatively small sample sizes within uncontrolled experimental designs, while others reflect the expertise of the sport-psychologist (Butler, 1989; Butler and Hardy, 1992; Butler et al., 1993; Jones, 1993; Dale and Wrisberg, 1996), rather than the psychometric utility of the Performance Profile (Doyle et al., 1998; Weston, 2005; Weston, 2008).

Butler and Hardy (1992) originally proposed that using this method of assessing athletes' perceived needs followed by a guided intervention management programme tailored to these perceived needs. However, there has only been one study conducted in 2011 (almost twenty years since the initial conception) using the first empirically randomised investigation design to examine the impact of repeated performance-profiling intervention on athletes' intrinsic motivation (Weston et al., 2011b). Moreover, the findings here suggested that single use of the Performance Profile failed to significantly improve athletes' intrinsic motivation, whereas intrinsic motivation improved significantly compared to the control group condition following three repeated completions during a competitive six-week season. While these findings should be viewed with caution, this first attempt to investigate the motivational responses of performance profiling to enhance motivation is encouraging. In view of this, the research conducted in this study used only a more rigorous scientific approach to assess a repeated performance profiling intervention on athlete's motivation, and there are a considerable number of research avenues **(APPENDIX 2**; p. 445**)** that require these levels of empirically-controlled investigations to substantiate the other claimed benefits of performance profiling.

In classifying the Performance Profile, this technique can be defined broadly into two categories, as both an 'assessment' phase which is then used as a 'management' intervention tool. As yet, however, the literature has yet to define these two different phases within the profiling procedures. Similarly, in accordance with the definition of a P-BOM, which is any outcome measure that is directly assessed from the patient's perspective of their health status without the interpretation of the patient's response by a clinician, it is deemed to be a patient assessment outcome measure (Deshpande, Rajan, Sudeepthi, and Abdul-Nazir, 2011). Therefore, for the purpose of this thesis, an assessment phase (as outlined below) for the Performance Profile will also adopt this definition. Therefore, when any individual (athlete or patient) completes a Performance Profile, and this profile is not interpreted by their coaches or clinicians, this process will be referred to as an assessment outcome. However, when a Performance Profile is interpreted, and then used as a means to manage subsequent training or rehabilitation, this process will be referred to as a management tool or outcome measure.

The first phases of the traditional Performance Profiling procedure (Butler and Hardy, 1992), are used as a means of raising an athlete's awareness of the qualities that are important to successful performance in an athlete's sport or sporting position. Within this initial stage of assessment, the Performance Profile allows individual athletes to report his or her own perceived needs, strengths and/or weaknesses (Butler, 1989; Butler and Hardy, 1992). Either deployed during an individual consultation, or combined within a groups of athletes, both methods involve a three-step process, producing either an individual Performance Profile for each athlete/patient with an individualised list of their own perceived needs, strengths or weaknesses or, collectively as a group, athletes can agree upon the qualities which the team consider necessary for their team as a whole[12].

At this stage, athletes may also select qualities and attributes previously identified collectively as a team from generated lists to produce an individualised profile[13]. Quite often, when the Performance Profile is used as an assessment outcome measure within a sport domain with athletes in preparation for competitive events, athletes report a combination of technical, tactical, physical, and/or psychological qualities related to each athlete's performance capabilities (Butler and Hardy, 1992). Following the completion of the Performance Profile initial assessment phase, a list of qualities or attributes identified as important for successful performance in their sport or position are mapped onto a Performance Profile chart. Typically, Performance Profiles are presented within a concentric circular arrangement **(FIGURE 3**; p. 56**)**.

Each athlete/patient would then be asked to rate the identified qualities essential to their performance, using a zero to ten scale. Conversely, Butler (1989) also sought to understand not only the athlete's perspective of what is considered important, but also the coaches' perspective of the athlete's performance and any areas in need of improvement. This is achieved by the coach performing a separate rating of the same qualities the athlete perceives to be important (Dale and Wrisberg, 1996; Weston et al., 2010). Therefore, following the completion of the respective performance profiles by the athlete (and in some instances by the athlete's coach), the athlete, athlete's coach and sports-psychologist are encouraged to discuss and compare the completed profiles. Any gaps or areas for improvement or maintenance can be easily observed thanks to the simplistic arrangement of the profiling outputs (Fransella, Bell and Bannister, 2004).

This mediation process is often used as the first step to formulating and setting goals (Butler, 1997), and structuring a suitable training programme that is oriented to the development of physical, technical, tactical, and/or psychological qualities which the athlete and coach perceive to be important (Butler et al., 1993; Jones, 1993; Weston et al., 2011a). The literature suggests that Performance Profiling is a suitable means of evaluating and monitoring performance over time (Butler and Hardy, 1992) and is able to develop an athlete's confidence (Butler, 1995), and may facilitate more self-determined motivation toward training interventions (Deci and Ryan's, 1985;

[12] Consult p. 182 for a comprehensive overview of Butler and Hardy's (1992) profiling methodology.

Butler and Hardy, 1992), all of which are suggested to be part of a shared decision-making process, encouraging communication between the athlete and his or her management team (Dale and Wrisberg, 1996).

Therefore, the justification for the use of the Performance Profile has been strongly linked and embedded within Personal Construct Theory (PCT) (Kelly, 1955)[14]. Additionally, as proposed by Butler and Hardy (1992), the importance of Deci and Ryan's (1985) Cognitive Evaluation Theory (CET)[15] is another theoretical framework that has justified the use of Performance Profile with athletes (Weston et al., 2013). In contrast, and as suggested more recently, Gucciardi and Gordon (2009) explained that Butler and Hardy's (1992) Performance Profile only incorporated some elements of PCT. For example, authors report that only four corollaries (Individuality, Commonality, Sociality and Organisation) within the conceptual framework are generally examined, with the remaining seven (Construction, Choice, Modulation, Experience, Dichotomy, Range and Fragmentation) corollaries are rarely assessed.

Subsequently, a 'revised' and 'extended' version of the Performance Profile procedure has recently been developed (Gucciardi and Gordon, 2009b) and is designed to attempt to understand all the key tenets of the personal construct psychology approach, which the authors argued that the traditional Performance Profile did not fully incorporate and, thus, attempts to understand the true perspective of an athlete (Gucciardi and Gordon, 2009a). However, this recent update of the Performance Profile procedure has been the most radical alteration of Butler and Hardy's (1992) Performance Profile approach and requires further evaluation to determine its usefulness within applied settings (Weston et al., 2013). Therefore, it is argued that the proposed newer and extended version might offer researchers and/or practitioners a means to further understand the content and structure of the individual's perspective and may be useful in developing a greater variety of interventions or guiding novel one-to-one consultations (Gucciardi and Gordon, 2009a; Gucciardi and Gordon, 2009b).

[14] Consult the Literature Review (p. 99) for a more detailed description of George Kelly's (1955) Personal Construct Theory.

[15] Consult the Literature Review (p. 99) for a more detailed description of Deci and Ryan's (1985) Cognitive Evaluation Theory (CET).

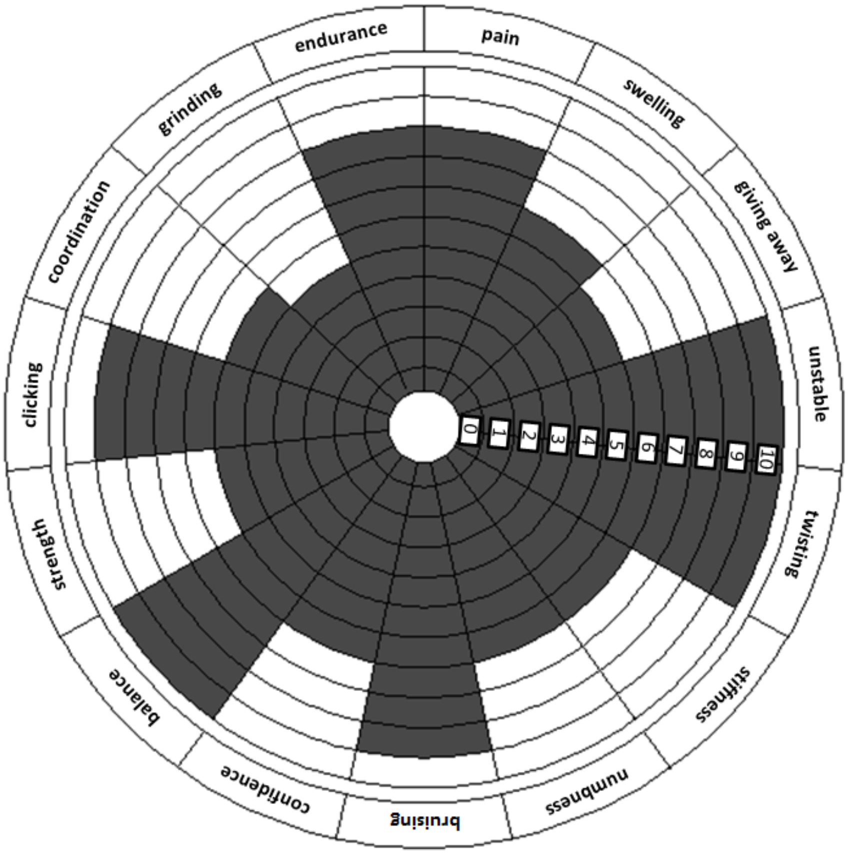

FIGURE 3 - Completed Performance Profile in a concentric circular design, with the qualities the participant perceives to be in need of rehabilitation and improvement displayed around the perimeter of the profile for the state of the injured limb on a scale of [0] 'my knee feels far from recovered' to [10] 'my knee feels fully recovered'). **NOTE:** Shaded area represents perceived current state (Source: Author's own diagram, edited with clinical data obtained from this thesis).

This new profiling procedure uses many of the underpinning theories associated with PCT[16] and somewhat parallels the original construction of the Repertory Grid technique. In criticism, the development of the original Performance Profile was adapted so that this approach could be completed quickly, whilst providing athletes and coaches with displayed information, which can be interpreted visually to gain a rapid understanding of the athlete's self-perceived strengths and weaknesses without the numerical interpretations that were required with the Repertory Grid technique (Butler et al., 1993). Therefore, it can be argued that the methodological procedures of Gucciardi and Gordon (2009a) appear to be more time-intensive to construct and analyse. As yet, the extended profiling procedure of Gucciardi and Gordon (2009a) has not been scientifically and empirically applied, or evaluated against the original profiling procedure of Butter and Hardy (1992) to verify its efficacy (Weston et al., 2013).

[16] Personal Construct Theory (PCT).

Furthermore, a compelling justification for the use of the Performance Profile are many of the claimed benefits set out in the literature **(FIGURE 4**; p. 58**)**, however, these are tenuous links, at best, and have rarely been investigated empirically to substantiate the claims. As initially reported within reflective commentaries and many case study examples (Butler, 1989, Butler and Hardly, 1992, Jones, 1993; Dale and Wrisberg, 1996), it was initially proposed that the main benefit of the performance profiling procedure was its use as a means to heighten an athlete's awareness of the qualities that are important to successful performance in an athlete's sport or sporting position, whereby, the athlete reports his or her own perceived needs, strengths and/or weaknesses (Butler, 1989; Butler and Hardy, 1992).

Considering all of the aforementioned claimed uses and benefits, as presented in **FIGURE 4** (p. 58), it is only recently that evaluative research within quantitative investigations has finally verified the impacts, uses and benefits of the Performance Profile from the perspective of athletes and accredited sport psychologists of the British Association of Sport and Exercise Sciences (BASES) (Weston et al., 2013). In brief, it was reported that athletes believed that the Performance Profile: **[1 :]** was particularly useful in raising an athlete's self-awareness in preparation for competition, **[2 :]** was a means of helping athletes decide which elements of performance needed to be worked on, **[3 :]** motivated athletes to improve, **[4 :]** aided athletes in setting appropriate and realistic goals, **[5 :]** provides a means of monitoring and evaluating athletes' own performance over time, while **[6 :]** allowing athletes to take more active responsibility for their own athletic development (Weston et al., 2011a). As regards the sport-psychologists' perceptions of the usefulness and impacts of the Performance Profile, the same perceived benefits and uses were also reported. However, sport-psychologists also believed that the profiling procedure was particularly useful in enabling athletes to identify their own strengths and weaknesses, whilst facilitating discussion and effective communication and interaction within teams themselves (Weston et al., 2011b).

In summary, all Performance Profiling studies to date, from reflective commentaries and the first attempts to assess the validity[17] and reliability[18] of the Performance Profile, to the more evaluative research reporting the uses, benefits and impacts of this profiling technique from the perspective of athletes and sporting-practitioners, have (Weston et al., 2011a; Weston et al., 2011b), overall, provided a useful preliminary insight into the Performance Profile's validity, reliability and benefits to athletes and practitioners applying this technique. However, further empirical

[17] Consult the literature review (p. 99) for a comprehensive review of the literature on the validity of the Performance Profiling Technique.

[18] Consult the literature review (p. 99) for a comprehensive review of the literature on the reliability of the Performance Profiling Technique.

investigations are required across a variety of sports before more substantive conclusions can be drawn (Doyle et al., 1998; Weston et al., 2013).

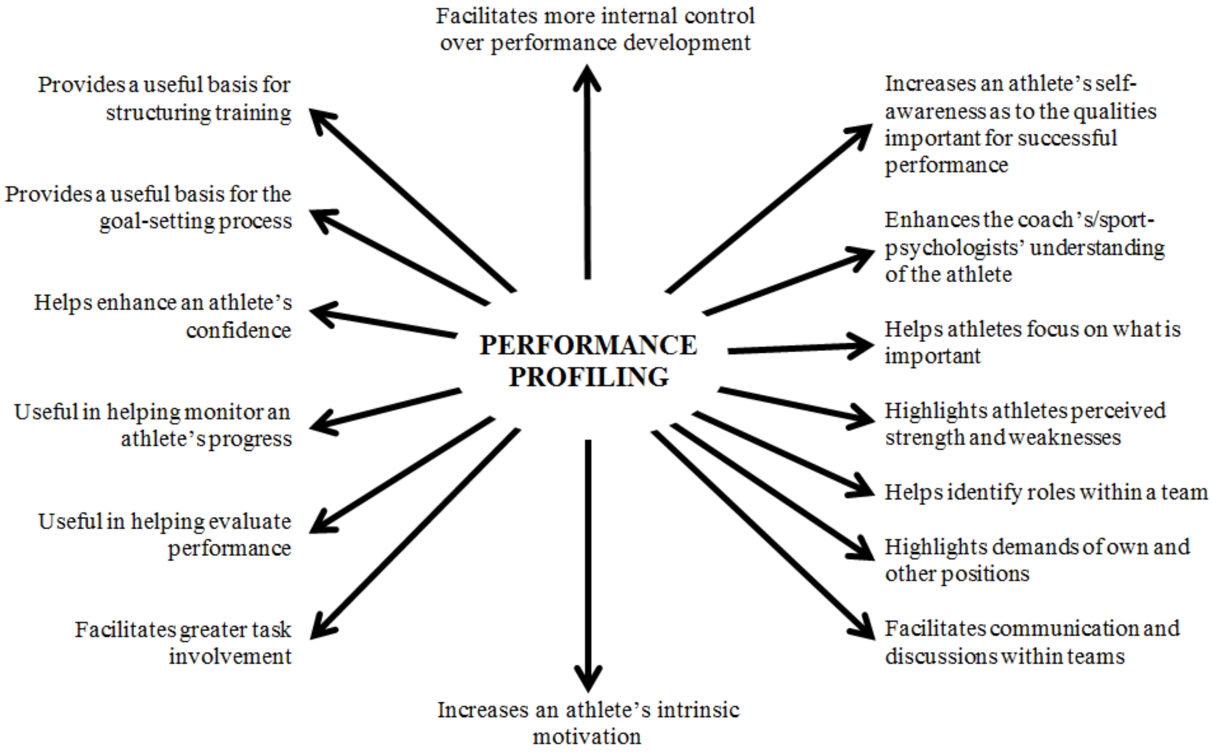

FIGURE 4 - A summary of the proposed benefits, impacts and uses of the Performance Profile as suggested by the literature (edited and adapted from Weston, 2008).

It should be pointed out that research studies have suggested that the Performance Profile should be used cautiously with all athletes (both recreational and elite), as it is unlikely that the Performance Profile has sufficient measurement sensitivity to accurately rate the relatively small changes in performance and perceived needs. Therefore, a more suitable application for the Performance Profile would be during heavy periods of training or during rehabilitation following injury, where significant changes in performance capabilities and perceived needs are likely (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Doyle, Gleeson et al., 1998; Gleeson, Parfitt, Doyle, and Rees, 2005). Indeed, within a clinical commentary, Doyle and Parfitt (1998) discuss the justification for incorporating the Performance Profile within a clinical setting, how this profiling technique could be adopted as a means to assess patients' perceived needs, and how these perceived areas for improvement could be used to manage patient care throughout a structured patient-centred rehabilitation programme **(FIGURE 5**; p. 60**)**.

In light of the above, no further investigations into similar empirical designs assessing the validity and reliability of the Performance Profile in athletic populations has been conducted despite continued advocation for its use. To enhance the technique's credibility, further investigations would be useful to validate the reliability and validity of the Performance Profile in a clinical setting, however, since this appears to be a more suitable application (Yates et al., 2016).

Following the recent transference of the Performance Profile to a clinical setting (Gleeson et al., 2008), no study has yet investigated its use as a management tool in this context, and only one randomised trial has investigated this use in athletes alone (Weston et al., 2011b), despite tremendous support for its use in both athletic research and within the athletic population itself (Doyle and Parfitt, 1997; Doyle et al., 1998; Gleeson et al., 2008; Weston et al., 2012). Moreover, no previous study has investigated use of the Performance Profile on any symptomatic population within orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways.

The application of the Performance Profile to a symptomatic population (i.e., ACL-deficient patients) has been proposed more recently (Doyle and Parfitt, 1997; Doyle et al., 1998; Weston et al., 2013) and, although limited, the preliminary literature and empirical evidence has provided a rationale and the novelty for this thesis to investigate the clinical utility and practical use of the Performance Profile (Doyle et al., 1998; Doyle and Parfitt, 1997; Gleeson et al., 2008; Yates et al., 2016). The potential inclusion of this profiling approach to other areas of rehabilitation with symptomatic individuals following injury, disease and/or illness is also conceivable. It can also be argued that the somewhat standardised nature of the ACLR surgeries performed and the standardised rehabilitation programme patients follow provide a suitable platform for investigating the Performance Profile in a relatively controlled setting.

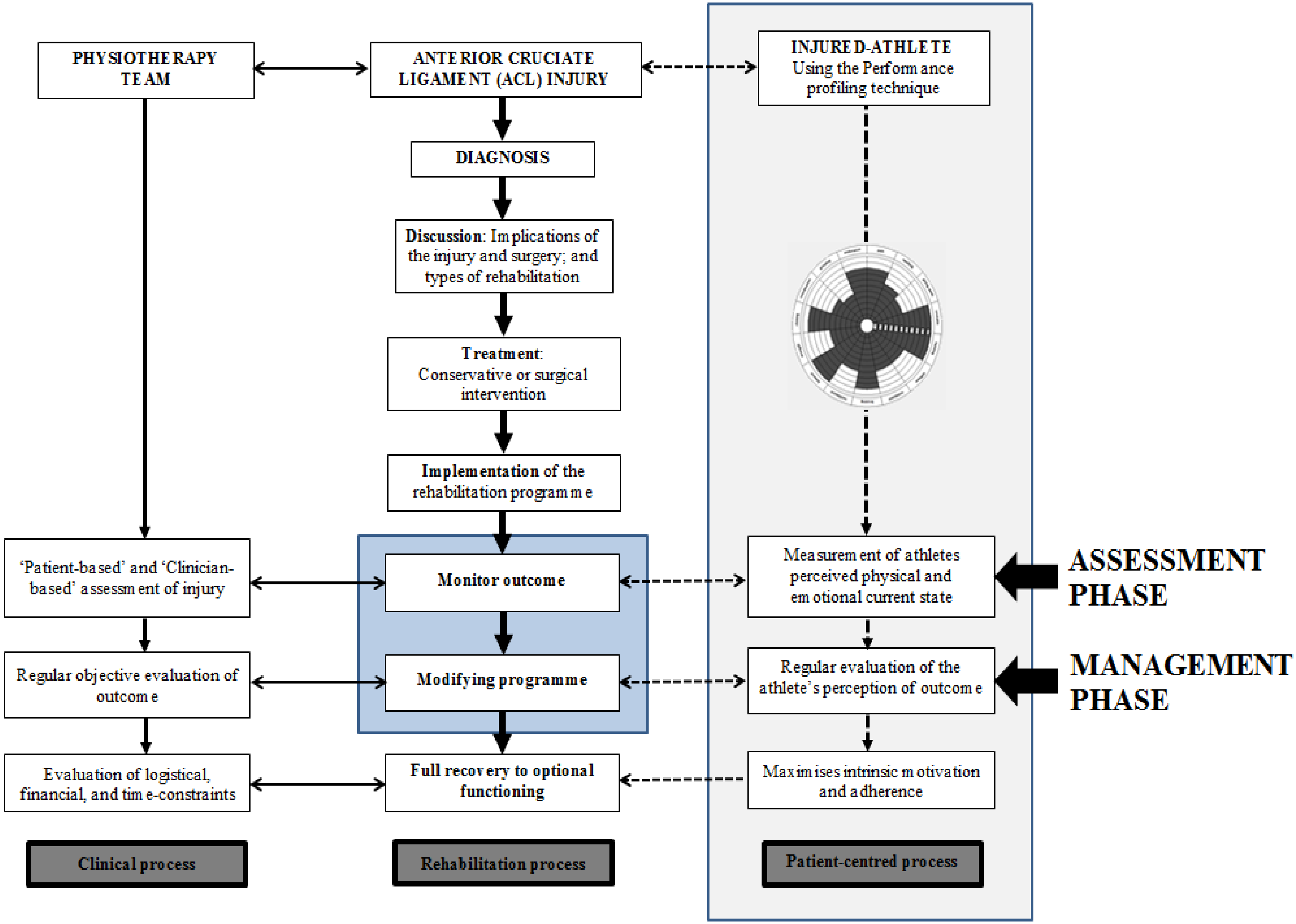

FIGURE 5 - Edited and adapted from Doyle and Parfitt (1998), showing the potential incorporation of the Performance Profile with a clinical setting and rehabilitation framework. **<u>NOTE</u>:** Performance Profile process within the shaded areas to the right of the flow diagram.

1.2 - Thesis aims and objectives

1.2.1 - Primary clinical research question

Currently, rehabilitation following ACLR surgery[19] benefits most patients and a minimum of 6 months' supervised rehabilitation is recommended with associated financial cost implications to the National Health Service (NHS). Patients are offered a standardised rehabilitation programme with limited adaptation of the service to individual patient needs. Therefore, the rationale for this thesis emanates from evidence supporting patient-centred approaches, individually tailored to self-perceived needs having greater efficacy on rehabilitation than standard approaches (Suhonen, Valimaki, Katajisto, and Leino-Kilpi, 2007; Kromer, de Bie, and Bastiaenen, 2010; Hanekom, Louw, and Coetzee, 2012).

The focus of attention will be on the knee and more specifically ACLR surgery since the ACL is one of the most common knee ligamentous injuries during sporting and occupational endeavours. Rehabilitation following ACLR surgery uses a protocol with proven efficacy in current clinical practice at the NHS Foundation Trust Orthopaedic Hospital, involving a standardised physiotherapy rehabilitation programme of care (RJAH, 2007).

The principal aim of the thesis is to investigate the effects of encouraging each patient to self-perceive and manage areas of physical self-perceived needs within standardised and periodic routine negotiations during scheduled physiotherapy appointments with the physiotherapist during rehabilitation following ACLR surgery, using a valid patient-centred, idiographic technique and a strategy termed the Performance Profile, developed by Butler and Hardy (1992) **(Study 4: Intervention RCT investigation)**. This negotiation process will potentially be a means of developing a more structured and enhanced patient-centred programme of care.

All participants devised an individualised Performance Profile within a two-week period prior to their ACLR surgery. The systematic deployment of the Performance Profile, prior to physiotherapy appointments, will provide a means for the physiotherapist (within an assessment phase) to perform a quantifiable evaluation of the self-perceived deficiencies identified by each patient[20].

Through the routine evaluation of their own Performance Profile (and a guided intervention management programme based on those needs), the care delivery pattern and content of the conditioning will be modified periodically through Performance Profile Management (PPM)

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[19] Anterior Cruciate Ligament (ACL) Reconstruction (ACLR).

[20] Developing and validating any new outcome measure (i.e., Performance Profile), it is necessary to address aspects of the psychometric measurement properties to substantiate the use of Performance Profile in clinical practice **(Chapter 6 [Study 3]: Reliability investigation)**, which has not been previously investigated. This process would determine the suitability of the Performance Profile for use in Study 4 **(Chapter 7: Intervention RCT investigation)** and in the evaluation of the primary research question.

rehabilitation group involving rehabilitation conditioning modified periodically through patient-physiotherapist negotiation to optimise attainment of the desired improvements.

Within the PPM rehabilitation group, each participant will be required to determine the relative importance of each self-perceived need, as in previous research (Weston et al., 2011b). They will be asked to rank their Performance Profile qualities/items in order of importance and those requiring greatest improvement (and priority of treatment) to obtain full recovery. The five areas identified from the ratings as most important from the patient's perspective will be used to initiate discussions between the patient and physiotherapist on how best to achieve the desired improvements from the patient's perspective. They will then negotiate and agree upon the content of any subsequent rehabilitation and treatment strategies (where clinically relevant) according to the factors determined previously that are essential to obtain full recovery.

In accordance with the ICF framework[21], the outcomes will be evaluated by a combination of P-BOMs[22] (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs[23] (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) to assess overall knee function following ACLR surgery **(**see **FIGURE 2**; p. 44**)** within contemporary practice. It is worth noting that the majority of P-BOMs and C-BOMs within this thesis (i.e., Single-Leg Hop for distance, IKDC, KOOS, and Lysholm) are currently deployed at the rehabilitation and physiotherapy centre (Robert Jones and Agnes Hunt Orthopaedic Hospital (RJAH), Oswestry, UK). In addition to these, and contrary to contemporary clinical practice, this thesis will examine the use of dynamometry, arthrometry and proprioceptive testing equipment in an attempt to understand the sensorimotor performance and neuro-musculoskeletal capabilities of patients during recovery and rehabilitation following their ACLR surgery (Gleeson and Mercer, 1996; Gleeson, Naish, Wilcock, and Mercer, 2002; Minshull et al., 2007).

1.2.2 - Research Hypothesis

- Null (*Ho*): The effect of Performance Profile Management (PPM) on the P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, SMP-FE, PF, EMD, and RFD), over a period of standardised clinical care, would be equivalent to that of contemporary (CON) clinical practice, in a clinical population undergoing knee ACLR rehabilitation.

[21] International Classification of Functioning, Disability and Health (ICF) model.

[22] Patient-Based Outcome Measures (P-BOMs).
[23] Clinician-Based Outcome Measures (C-BOMs).

- Alternative: The experimental hypothesis is that the effect of Performance Profile Management (PPM) on the P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, SMP-FE, PF, EMD, and RFD), over a period of standardised clinical care, would offer superior outcomes to those delivered by contemporary (CON) clinical practice[24], in a clinical population undergoing knee ACLR rehabilitation.

1.2.3 - Secondary clinical research question

The relative importance of outcome measures (P-BOMs or C-BOMs) required to deliver a global assessment and manage patients' post-ACL injury care, remains unknown (Phillips et al., 2000). Therefore, the secondary clinical question of the thesis is to describe and understand the relationship amongst P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, RFD, PF, EMD, and SMP-FE). Firstly, understanding the inter-correlations among: **(1 :)** P-BOMs; **(2 :)** C-BOMs; and **(3 :)** P-BOMs and C-BOMs together, before ACLR surgery, and within acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) rehabilitation phases could allow speculation over the number of outcome measures needed to correctly describe progression, and provide an understanding of the hierarchy of importance of the outcome measures, enabling changes in functional capacity to be properly described.

The novelty of this thesis (and this secondary question) is firstly the addition of the Performance Profile with these three inter-correlations (P-BOMs, C-BOMs, and P-BOMs and C-BOMs together), providing insight into the correlational characteristics of the Performance Profile evaluated against commonly deployed P-BOMs and C-BOMs longitudinally across 24 weeks of rehabilitation (Gleeson et al., 2008; Yates et al., 2016), and allowing further commentary on the introduction of the Performance Profile into clinical practice. The second novelty is the investigation into the use of the contralateral (non-injured) limb as a control leg[25]. The evaluation included the knee flexors and knee extensors of both the injured and non-injured limbs. Indeed, the inclusion of a control limb has yet to be thoroughly presented in correlational studies to date (Sernert et al., 1999) and its evaluation by the Performance Profile will allow an understanding of the differences between the limbs. Although a degree of physiological deconditioning of the non-injured leg is expected due to altered physiological loading in the period between injury and surgery,

[24] Although it is difficult to establish from previous research an agreed Minimal Clinically Important Difference (MCID) (see p. 166) for P-BOMs and C-BOMs, it can be suggested that an up to 15% improvement following the PPM interventions post-ACLR surgery might represent sufficient clinical efficacy to validate its application in clinical practice (Davidson and Keating, 2014).

[25] When attempting to identify levels of 'normal' or improved function brought about by ACLR surgery and subsequent rehabilitation, the use of the contralateral asymptomatic leg as a baseline and control is prevalent and indeed, was used in this way in Study 3 **(Chapter 6)** and Study 4 **(Chapter 7)**.

the inclusion of this leg nevertheless represents a best estimate of a reference (baseline) for performance and functional capability following ACL injury.

1.2.4 - Research Hypothesis

The strength of correlations and magnitude of relationships remains relatively speculative, warranting further investigation. However, the following hypothesises are anticipated.

(1) It is firstly hypothesised *a priori* that the inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would demonstrate the highest strength of correlations compared to C-BOMs (i.e., Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE). This is anticipated since the P-BOMs used (as above) address similar facets and sub-components of dysfunction and disability (i.e., pain, symptoms, function, QoL, etc.) within the inventory of questions asked, therefore greater convergence[26] is to be expected.

(2) It is secondly hypothesised *a priori* that the inter-correlation among C-BOMs (as above) at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would inter-correlate, but to a lesser extent due to the very disparate nature of the outcome measures used.

(3) Thirdly, it is further hypothesised *a priori* that the inter-correlations among P-BOMs and C-BOMs measured concomitantly at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would demonstrate a lesser strength of correlations compared to P-BOMs and C-BOMs evaluated in isolation. This was anticipated as P-BOM and C-BOM outcomes quantify different aspects of recovery and function (disability versus impairment respectively) and are therefore reasoned to be weakly correlated.

At the present time, there is insufficient research data to allow the relationships amongst P-BOMs, amongst C-BOMs, and between P-BOMs and C-BOM to be speculated with any degree of certainty, thus highlighting the challenges faced by clinicians and researchers. These include determining the minimum number of either P-BOMs or C-BOMs required to properly describe changes in patients' functional or physical performance during their rehabilitation, and importantly, the dilemma of whether P-BOMs or C-BOMs offer most validity **(**see Reiman and Manske, 2011**)**. Ideally, if this research does support a strong relationship among P-BOMs and C-BOMs evaluated concomitantly, this might indicate that patients are indeed correctly scoring their own perceptions

[26] A parameter often used in Sociology, Psychology, and other Behavioral sciences, refers to the degree to which two measures of constructs that theoretically should be related, are in fact related (Howell, 1998).

of capability (P-BOMs) versus their objective physical performance, as evaluated by C-BOMs. These correlations would then support the future proxy use of P-BOMs as efficient substitutes for more complex C-BOMs, which may allow another means to assess a patient' outcomes in a less pragmatic way. Furthermore, if strong relationships are found amongst the candidate outcome measures, this could lead to a reduction in the number of P-BOMs and C-BOMs required to assess patient outcomes following ACLR surgery in the future.

CHAPTER TWO

LITERATURE REVIEW

2.1. - Literature Review

The preceding introductory chapter has outlined and summarised the topic area as a whole and provided some pertinent background information to inform the subsequent chapters. The purpose of this chapter will be to present a comprehensive and systematic overview of the literature to date concerning the thesis. Throughout this thesis, the reader will be directed to this literature review if further explanation and detail are needed to support information within the main body of each following chapter and study. More specifically, this chapter will be divided into four main sections, each of which are related to the main chapters within this thesis.

2.2 - Patient-Centred Care and Shared-Decision Making

2.2.1 - Patient-Centred Care

In recent years, physiotherapy practice has encouraged healthcare professionals to become Evidence-based (Langendoen, 2004) and they are continually required to utilise an Evidence-based approach within their own physiotherapy practice (Huijbregts, 2005; Suter et al., 2007). In the process of promoting Patient-Centred Care (PCC), patient-centeredness has been reported to build on the following three cornerstones within physiotherapy: **(1 :)** Evidence-based practice, **(2 :)** experience and clinical reasoning with patient preferences, and **(3 :)** practical, patient centred application (Tuttle, 2009; Langendoen, 2004). An Evidence-based approach is broadly defined as the judicious use of the best current evidence, and using this evidence in making appropriate decisions about the care of the individual patients (Sackett et al., 1996). The concept and controversies of Evidence-based practice for rehabilitation professionals has been extensively reviewed (Dijkers et al., 2012). When making treatment interventions, it is essential that all healthcare professionals integrate their own clinical expertise with respect to both the best available current research evidence and patient preferences and opinions (Straus, Richardson, Glaszious, and Haynes, 2005).

Likewise, within the field of physiotherapy, a more detailed understanding of patients' preferences and involvement within a patient's own treatment strategies, and verifying the circumstances in which rehabilitation might be enhanced by empowering the patient to play a key role in shaping treatment and leading to his or her own recovery may be necessary, in order that the patient and physiotherapist can reach an effective shared clinical decisions, and to allow the patient and physiotherapists to set realistic shared rehabilitation goals (Schoeb et al., 2014). More importantly, the concept of shared decision-making process between the patient and the physiotherapist has been an integral component of patient-centred approaches (de Haes, 2006), and has been a patient-based-aligned approach in strengthening such PCC as in medical rehabilitation (Faller, 2003). Essentially, communication is considered a central component of patient-centred care (Bensing et al., 2000; Cooper et al., 2009) and, more recently, the concepts of both patient-centeredness and the shared decision-making process have been advocated as the starting points of effective communication for the delivery of PCC (Ishikawa et al., 2013).

Finding a consistent definition of PCC is a challenge because of the high frequency of the use of differing interchangeable terminologies in the literature (McCance et al., 2011). This is particularly problematic given the different meanings of the terms patient-centred (i.e., 'client-centred', 'patient-focused', 'tailored' and 'individualised', to name a few) exist and these differing terminologies are used frequently and interchangeable between many medical disciplines. The term patient-centeredness seems to be an overarching expression that includes all of these terms (Suhonen et al., 2007). However, it has been suggested that it is impossible to demonstrate the extent to which physiotherapy is indeed patient-centred and, therefore, to assess the possible benefits of such a patient-centred approach, in the absence of a clear definition (Cooper et al., 2009).

There is, currently, much interest in how the effective delivery of an Evidence-based approach should be utilised within the field of physiotherapy. An important issue in the area, which often overlaps with evidence-based practice, is the concept of PCC (Bensing, 2000). At present, it seems unclear as to precisely how PCC should be adopted into physiotherapy practice and how physiotherapists can effectively integrate this approach into their own daily practices (Cooper et al., 2009; Ishikawa et al., 2013). Moreover, there have been some concerns that PCC, which has focused on individualised perceived needs, might be at odds with an Evidence-based approach which has tended to focus on populations as a whole and is not addressing individual patient preferences and perceived needs (Epstein and Street, 2011). It is argued that Evidence-Based Medicine should acknowledge that a good clinical outcome must be defined in terms of what is meaningful and valuable to the individual patient. Thus, Evidence-Based Medicine and Patient-Centred Care are intrinsically linked (Guyatt et al., 2004).

Evidence-Based Medicine is firstly reported as the integration of individual expertise of clinicians with the use of validated scientific evidence which allows for the optimal treatment of patients (Sackett et al., 1996). Secondly, Patient-Centred Medicine is a field working alongside the concepts of personalised medicine and tailored therapeutics (Sacristán, 2013). Meyer (2012) defines the main objectives of Patient-Centred Medicine is to improve health outcomes of individual patients throughout clinical practice, while taking into account the patient's goals, preferences and values, as well as the available economic resources. With these definitions in mind, it has been argued that Evidence-Based Medicine is not truly a patient-centred approach (Bensing, 2000). Here, the author argues that Evidence-Based Medicine is in fact disease-oriented and not patient-oriented (Sweeney, Macauley, and Gray, 1998). Furthermore, to 'bridge the gap' between both paradigms of Evidence-Based Medicine and Patient-Centred Medicine that Evidence-Based Medicine should include research based on patient preferences in randomised controlled trials; and also, patient-centred medicine should become more Evidence-based by focusing more research investigating effective communication strategies in their study designs (Torgerson and Sibbald, 1998).

In recent years, it has been extensively acknowledged that the underlying principle for the delivery of effective health and rehabilitation services is that clinical practice should be patient-centred (Potter, Gordan, and Hamer, 2003). With this in mind, healthcare professionals are to encourage patients to actively participate in, and share control of, treatment and management decisions that take into account their individual preferences, opinions and values (Holliday et al., 2007). In a 'patient-centred care model' **(**see **FIGURE 1**; p. 38**)**, the concept of patient-centred care is defined as an equal partnership between the clinician and patient. Within this conceptual model, patient-centred care places the patient centrally within the professional relationship and, furthermore, supports the notion that an understanding of the patient's perspective should underpin good practice in an equality-based therapeutic relationship (Kidd et al., 2011).

2.2.2 - Shared Decision Making

Alongside this line of argument, the appropriate use of clinical reasoning and judgement in conjunction with a shared decision-making process are considered fundamental (Vranceanu et al., 2009; Smith et al., 2007). Importantly, the concept of a shared decision making process between a patient and a clinician has been reported to be an integral component of the effective delivery of patient-centred care (de Haes, 2006) and, also specifically in the field of medical rehabilitation by physiotherapists (Faller, 2003). In practical terms, for a physiotherapist to deliver true patient-centred rehabilitation, rehabilitation plans should be prospectively discussed with the individual patient during a goal-setting discussion. In this discussion, the patient's expressed needs, goals and expectations are identified and documented, with a view to informing the decision-making processes regarding the rehabilitative care programme (Ozer et al., 2000; Wohlin-Wottrich et al., 2004).

The conceptual framework for the involvement of patients within the decision-making process has been extensively reviewed (Entwistle and Watt, 2006). However, as reported by Dierck et al., (2013), physiotherapists often do not incorporate patient preferences or values within their decision-making process, or even allow patients to provide their opinions about the proposed treatment plan. It can be argued, however, that the inclusion of patient needs and preferences within the decision-making process may not always be suitable and could be clinically inappropriate (de Haes, 2006). Therefore, the inability of a patient to participate fully in his or her own rehabilitation programme of care, whereby, patients are unable to effectively contribute to their own rehabilitation programme of care. Further, in turn patients' needs and preferences which are not considered, due to their being clinically inappropriate, can subsequently influence the level of patient-centeredness within the patient-clinician relationship, as patients themselves are unable to participate in their own care (Leach et al., 2010). Therefore, if patient views and preferences are not integrated within the decision-making process about treatments interventions, then patients may be less likely to adhere to their rehabilitation programme. This may result in reduced motivation, cooperation and dissatisfaction that may ultimately prevent patients from achieving optimal recovery (Bowling and Rowe, 2005).

Within the empirical research to date, which is limited, the concept of patient-centred care remains a complex interaction and is a contested issue requiring additional research (Mead and Bower, 2000; Gillespie et al., 2004). Within the specific field of physiotherapy, it remains unclear precisely what is meant or understood by the term 'Patient-Centred Care' (PCC) and how this can be implemented effectively in clinical practice (Cooper et al., 2009). Arguably, a more detailed understanding of patient preferences for treatment is necessary in order to achieve an effective shared clinical decision, and to allow the patient and the physiotherapist to set realistic and desired rehabilitation goals (Schoeb et al., 2014). Within the specific field of orthopaedic physiotherapy, the limited empirical research has yet to investigate how the process of goal-setting can be effectively achieved, and how this process of goal-setting between a patient and physiotherapist may affect the patient-centred approach (Schoeb, 2009). In summary, it has been suggested that a patient's involvement within goal-setting, and including patients within the shared decision-making process, should improve patient satisfaction, adherence to rehabilitation, and health outcomes. In this respect, this concept would appear to be a prerequisite for good clinical practice, even though the current evidence remains limited (Dierck et al., 2013). The literature regarding patient preference for different treatment options, where alternatives exist, is sparse and the concept requires further investigation (Bowling and Ebrahim, 2001).

The delivery of physiotherapeutic treatment strategies varies substantially within physiotherapy practice, and this explanation has been reported to describe the reasons for the discrepancies in healthcare outcomes (Lutfey et al., 2008). Physiotherapists have access to a multitude of manual therapies and modalities which need to be applied in a problem-solving approach. A single treatment intervention is rarely, if ever, implemented (Langendoen, 2004; Shiell et al., 2008). More often, a structured rehabilitation programme will be developed, which follows a standardised approach that is subsequently individualised to each patient's needs and is, generally, an evidence-based and milestone-driven protocol (Heijne et al., 2008). A continuing challenge for physiotherapists is to devise the most rapid, effective and individualised recovery process to restore patients to a pre-injury status (Langendoen, 2004).

Patient-Centred Medicine, however, is a newly evolving field and is developing alongside the concepts of personalised medicine and tailored therapeutics (Meyer, 2012). Patient-Centred Medicine implies a paradigm shift in the relationship between healthcare professionals and their patients, whereby, for physiotherapists the fundamental changes are not required in the individuations of treatment strategies, but are more within the individualisation of therapeutic decisions, where the patient's preferences and perceived needs play an essential role (Sacristán, 2013). There is a limited body of evidence in support of the assertion that patient-centred approaches that individually-tailor interventions, based on individual perceived needs, will have greater efficacy on rehabilitation than would standard care (Suhonen et al., 2007; Kromer et al., 2010; Hanekom et al., 2012).

The literature regarding patient preferences, including the evaluation of patients' perceived needs, opinions and values for treatment options, where alternatives exist, are sparse and require further investigation (Bowling and Ebrahim, 2001). The requirement for individualisation of patients' therapeutic content to achieve optimal outcomes is still widely recognised and advocated within the field of physiotherapy and the orthopaedic literature. However, the required large-scale randomised trials to confirm the efficacy of such individualised interventions remain opaque (Cott, 2004; Freeman, Hill and Car, 2004; Mead and Bower, 2002; Suhonen et al., 2002).

Patient involvement, direct from patient preferences and values in mind and a shared-decision process, has been suggested to improve patient satisfaction, adherence to rehabilitation, and health outcomes; all of which are known as prerequisites for good clinical practice (Dierck et al., 2013). The literature regarding patients' preferences for treatment options, where alternatives exist, are sparse and require further investigation (Bowling and Ebrahim, 2001). If the patients' views and preferences are not integrated in decision-making about treatments, then patients may be less likely to adhere to decisions. This may result, potentially, in reducing motivation, co-operation and dissatisfaction that may ultimately detract patients from their optimal recovery (Bowling and Rowe, 2005).

There is a body of evidence in support, although limited, for the assertion that patient-centred approaches that individually-tailor any interventions programme of care will have a greater efficacy on rehabilitation than standard care (Suhonen et al., 2007; Kromer et al., 2010; Hanekom et al., 2012). Despite this, little is known about the extent to which individualised care is implemented, the efficacy of such individualisation, and the factors that help or hinder healthcare professionals in optimising a patient's recovery (Suhonen et al., 2002; Heijne et al., 2008). The requirement for individualisation of patients' therapeutic content to achieve optimal outcomes is still widely recognised and advocated within the field of physiotherapy and orthopaedic literature however still requires large-scale randomised trials to confirm the efficacy of such interventions (Cott, 2004; Freeman et al., 2004; Mead and Bower, 2002; Suhonen et al., 2002).

2.3 - The Knee Joint, Anterior Cruciate Ligament (ACL), and ACL Rehabilitation

2.3.1 - The Knee Joint

The knee (trochoginglymoid) joint is formed by the articulation of the distal femur, proximal tibia, and the patella bone that make up the three compartments of the knee joint, known as the medial tibio-femoral, lateral tibio-femoral, and patella-femoral compartment, respectively; all of which share a common synovial cavity (Beasley et al., 2005). The two medial and lateral tibio-femoral interactions conform to make femorotibial joint at the knee; the largest joint in the human body (Goldblatt and Richmond, 2003). Therefore, the articulation of the femorotibial joint is maintained in part by the bony anatomy of the femoral condyles and the tibial plateau (Gregory and Fanelli, 2003).

Furthermore, within the joint space between the adjacent femoral condyles and corresponding tibial plateaus, two crescent-shaped wedges of fibrocartilage, known as menisci, are located on the medial and lateral aspects of the knee joint. The menisci increase the contact area, aid in shock absorption, provide lubrication, and assist in providing stability of the knee joint (Makris, Hadidi, and Athanasiou, 2011). Within the knee joint system **(**see **FIGURE 6)**, four ligaments provide most of the joint stability, consisting of the anterior cruciate ligament (ACL) and Posterior Cruciate Ligament (PCL); which prevent anterior and posterior translation of the tibia on the femur. The other two remaining ligaments are the Medial Collateral Ligament (MCL) and Lateral Collateral Ligament (LCL) that resist varus and valgus movements (Davenport, 2010).

Among the contributors to knee joint stability, the ACL is considered the primary passive restraint to anterior translation of the tibia with respect to the femur (accounts for approximately 86% of the total resistance to anterior tibial translation) (Butler, Noyes, and Grood, 1980), but also to limiting the excessive internal and external rotation of the tibia and varus or valgus stress of the tibia in the presence of collateral ligament injury (Beasley et al., 2005).

The primary action and movement of the knee joint is flexion and extension which varies and allows up to 160 degrees of flexion and five degrees of hyperextension as seen in the sagittal plane (Butler et al., 1980). At full extension, the screw-home mechanism locks the knee in full extension which allows the knee joint to be maintained in a rigid position allowing minimal energy expenditure. The knee joint is inherently unstable and can be easily injured because of its location between the two longest bones (femur and tibia) of the skeletal system, combined with the knee joint being a major weight bearing joint; making the knee joint more susceptible to injury (Andrews, Harrelson, and Wilk, 2012).

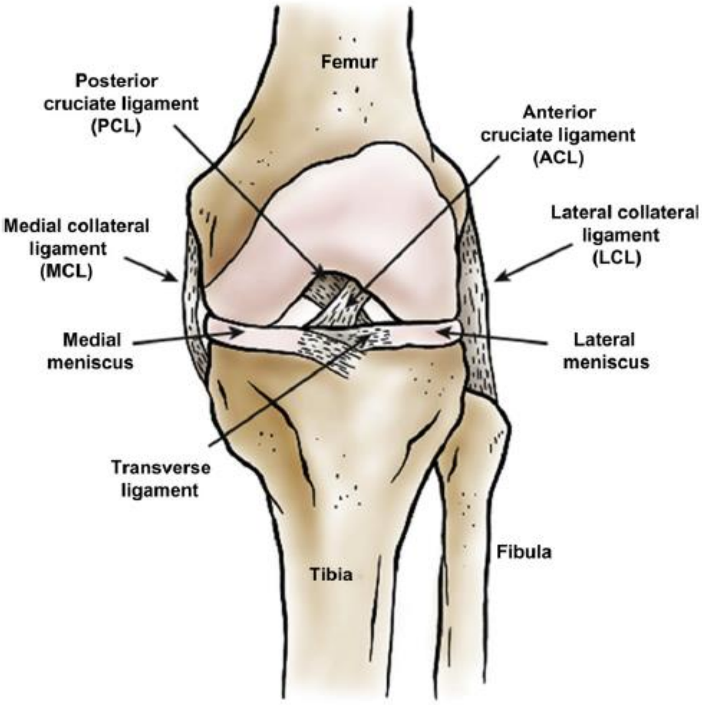

FIGURE 6 - Anatomy of the knee joint - edited and adapted from Makris et al., (2011). (Anterior view). **NOTE:** the knee meniscus situated between the femur and the tibia, with the various ligaments crossing, which all aid in the stabilisation of the knee joint system.

The dynamic stability of the knee joint is maintained via both static restraints (i.e., ligaments located within and around the knee joint) and active neuromuscular restraints (i.e., muscles surrounding the knee joint) (Kiapour et al., 2014). Neuromuscular control is defined as the unconscious state of activating (efferent response to an afferent signals) of activating dynamic restraints (joint stability) surrounding a joint in response to sensory stimuli (Alentorn-Geli et al., 2009). The mechanism of neuromuscular control of the knee joint involves a complex interaction of the afferent and efferent neurological system and associated muscles that control the knee joint (Silver and Mandelbaum, 2007). It has long been known that an ACL rupture disrupts static and dynamic knee restraints, compromising functional stability of the knee joint as well as reduced proprioception capability of the knee joint, therefore, the deficiency in neuromuscular control explains the increased risk of ACL injury (Griffin et al., 2006).

The structural complexities of the ACL reflect its important contribution to knee-joint function (Goldblatt et al., 2003). The ACL is a band-like collagenous structure that is approximately 31 to 38 mm in length and approximately 10 to 12 mm in width (Micheo, Hernandez, and Seda, 2010). The ACL originates and extends from a broad area anterior to, and between, the inter-condylar eminences of the tibia, and inserts into a semi-circular area on the posteromedial portion of the lateral femoral condyle (Kweon, Lederman, and Chhabra, 2013). Within this ligamentous structure, this intra-articular ligament (also encased within its own synovial membrane) is principally constructed from two dense bundles of connective tissues, known as the Anterio-Medial (AM) bundle (this becomes rigid in flexion) and the Postero-Lateral (PL) bundle that becomes rigid within an extension movement; which are enclosed within the knee joint capsule (Kweon et al., 2013). However, the two ACL fibres act synergistically with individual insertion points, with a variable axis and constant length, within the distal and proximal insertions of the ligament, tightening at different angles of the knee range of motion, making the ACL ligament overall an isometric knee stabiliser (Hernandez, Micheo, and Amy, 2006). Uncommon and rarely reported, a third intermediate bundle has been reported to account for up to 26% of knees. However, generally, it is accepted that the native ACL ligament contains two separate bundles (Takahashi, Doi, Abe, Suzuki, and Nagano, 2006).

The ACL is the most commonly injured and reconstructed ligament of the knee joint (Beynnon, Johnson, Abate, Fleming, and Nichols, 2005). However, the risk of suffering an ACL injury in the general UK population is reported as low (Fithian et al., 2005), but the incidence of injury within sports is considered considerably higher (Gianotti, Marshall, Hume, and Bunt, 2009). Determining the incidence rates can vary around the World, and determining the incidence of ACL injuries remains difficult when comprehensive incidence injury and registries are not set in place. However, it is estimated that 1 in 5,000 individuals are injured per year (estimated total costs of ACLR: £3,000 per surgery) in the United Kingdom, with 1 in 3,000 reported from within the United States (Mather et al., 2013) with estimated costs of $4,872 - 5,465 (Nagda, Altobelli, Bowdry, Brewster, Lombardo, 2010).

The mechanism of ACL injury is typically categorised as either a contact or a non-contact mechanism (injury); a contact injury is defined as contact with an opposing force either from another apposing sport performer or another object (i.e., playing surface such as grass) resulting in the ACL injury. It has been reported that only 30% of ACL injuries are due to contact mechanisms, whereas, the non-contact mechanism of injuries accounts for the remaining 70% of all ACL injuries (Alentorn-Geli et al., 2009). Examples of a contact injury occur when a sport performer is typically decelerating, combined with a change of direction with the foot in close-chain position (i.e., in contact with the floor). With the foot in this position and if the sport performer attempts to change direction quickly, the resulting forces (i.e., excessive torsional force) could injure the ACL. Conversely, a non-contact injury generally occurs with a sudden stop, change in direction, or landing from a jump where inadequate knee and hip flexion to aid landing, or a lapse of concentration due to an unanticipated event, such as a change in the direction of play, occurs (Silvers and Mandelbaum, 2011).

2.3.2 - Anterior Cruciate Ligament (ACL) Reconstruction (ACLR)

Advances in contemporary practice for surgical reconstruction of the ligamentous tissue after rupture, have meant that many sport performers can reasonably expect to return to sport again. Two meta-analysis studies reported that 67 to 76% of patients following ACLR surgery at 1-year were able to return to pre-injury levels of activity (Biau, Tournoux, Katsahian, Schranz, and Nizard, 2007). However, more recently reported, the actual return to pre-injury sport levels following ACLR are less than might be expected, and it appears that there is still a rapid decline in sporting participation after 2 - 3 years, post-ACLR surgery (Feller and Webster, 2013).

While surgical reconstruction techniques (Tompkins et al., 2012), graft types (Li et al., 2012), and placement and fixation methods (Kim et al., 2011), combined with numerous rehabilitation protocols (Escamilla, Macleod, Wilk, Paulos, and Andrews, 2012), have all undergone a rapid and global evolution over the past 25 years (Levy and Stuart, 2012), there still continues to be a debate about their clinical effectiveness (Lobb, Tumilty, and Claydon, 2012; Manske, Prohaska, and Lucas, 2012). More so, returning to sport after ACLR surgery remains a challenge and requires further investigation (Martin, Gard, Besson, and Menetrey 2013).

In ACLR, the ruptured ACL is surgically removed from the knee and replaced with a graft-like material with various graft options available. The appropriate graft selection requires consideration of many factors, which must be discussed on an individual basis with the patient and surgeon. Factors such as patient's age, activity level, and post-operative physical goals (i.e., returning to competitive sports) and previous surgeries must be considered prior to ACLR surgery (Razi, Sarzaeem, Kazemian, Najafi, and Najafi, 2014). Graft selections are, generally, categorised as auto-graft, allo-graft, or synthetic graft types (Li et al., 2012).

2.3.3 - Post-operative ACL rehabilitation

The rehabilitation of a patient with ACL injury often presents with complex issues of a multi-factorial nature, requiring various treatment interventions by different clinicians, working within a multidisciplinary practice (Hurn et al., 2006). Exercise prescription is a fundamental part of physiotherapy care and an important element in an ACL rehabilitation programme of care. Other treatment strategies used by physiotherapists range from electrotherapy and thermal modalities to manual therapies (Bronfort et al., 2010); all frequently deployed and used in combination throughout any part of the rehabilitation programme.

The literature indicates large differences in clinical and outpatient protocols involved within the ACL rehabilitation, which suggests, overall, that there is no agreed consensus regarding a programme of rehabilitation following ACLR surgery (van Grinsven, Van Cingel, Holla, and Van Loon, 2010; Karasel et al., 2010; Kvist, 2004; Trees, Howe, Dixon, and White, 2005). However, the therapeutic content, in terms of rehabilitation aims and recommended exercises and progressions, must be individualised to the needs of the patient (Heijne et al., 2008). More often, the structured rehabilitation programme will be developed, which will follow a standardised approach that is subsequently individualised to each patient's needs and is, generally, an evidence-based and milestone-driven protocol (Heijne et al., 2008). An example of a rehabilitation milestone programme (RJAH, 2007) can be seen in **APPENDIX 1** (p. 440).

Following ACLR surgery, rehabilitation aims to regain mechanical knee-joint stability and subsequently to rehabilitate the knee joint to a safe return to strenuous physical activity and, if required, a return to sport (Holsgaard-Larsen, Jensen, and Aagaard, 2014). In recent years, there has been a move from a traditional rehabilitation programme (9 to 12-month recovery period) (Risberg, Lewek, and Snyder-Mackler, 2004) to more aggressive and accelerated milestone-driven guidelines that are achieved within a shorter period of time, typically, within a 4 to 6-month period of recovery (Van-Grinsven et al., 2010; Silva, Sampaio, and Pinto, 2012).

Within an accelerated programme, common rehabilitation aims are to reduce post-surgical complications (i.e., reducing knee stiffness, difficulty in gaining full extension, and reducing the loss of muscle strength) (Shelbourne and Nitz, 1990). However, within this accelerated rehabilitative programme, similarly as in traditional ACL rehabilitation, it is important to reduce post-surgical complication associated with surgery as soon as possible (i.e., pain and swelling), while reducing other previously mentioned complications without causing damage to the healing graft. However, and more so, progressing to the next milestone rehabilitation protocol earlier, and allowing for a potential accelerated rehabilitation within a shorter time-frame, may have important implications for clinical practice (i.e., quicker return to employment, return to sport, and time-saving for patients during long-term rehabilitation programmes).

2.4 - Assessment and use of outcome measures in clinical practice and research

2.4.1 - Outcome Measures

Rehabilitation is a problem-solving and educational process that requires the use of 'assessments' conducted by healthcare professionals in order to identify the relevant problems. Within the field of physiotherapy, physiotherapists are the specialists who are required for the management of movement disorders or for dysfunction of the neuromusculo-articular system (Langendoen, 2004), and within their roles are required to analyse and classify the patient's functional disorder in daily life ('disability'), and subsequently to identify physical 'impairments' possibly related with the presented injury at the time of assessment (Gulick and Yoder, 2002).

The term 'assessment' includes the techniques and procedures for the classification and measurement of a variable pertaining to a patient (Tesio, 2007). During the rehabilitation process of a patient, for example following ACLR surgery, it is important for physiotherapists to assess and quantify a patient's progress over time and these measurement tools are labelled as 'outcome measures' (Irrgang and Lubowitz, 2008). Outcome measure can be used to assess and quantify the level of disability and impairment; within this 'functional assessment' outcome measures can be used to assist in the decision-making process that has resulted from an interaction from both a physical objective examination of a patients (i.e., diagnostic test) to the understanding of a patients perceived needs, aiming to recognise, anticipate or modify a course of treatment to optimise patient care (Tesio, 2007).

Historically, the use of outcome measures was not an integral part of routine clinical practice with physiotherapists (Tuttle, 2009). In the past, physiotherapists assessed the effectiveness of their clinical practice from observations either through the objective examination and/or from the patient's perspective as either been measure by patient satisfaction (or dissatisfaction) with the physiotherapy treatments (Mehta and Grafton, 2014). However, in the past two decades, there has been an increasing emphasis placed on Evidence-Based Medicine in physiotherapy (Nicholas, Hefford, and Tumilty, 2012). Likewise, the accountability of all healthcare organisations and providers in conjunction with all healthcare professionals, including physiotherapists, is now including their physiotherapy practice, while providing evidence for effectiveness of their therapeutic treatments, and in this context they are required to measure patient satisfaction (Zelle et al., 2005). In general, outcomes measurements are essential for the evaluation of patients and for the optimising of patient care and delivery, thus, the importance of outcome measures is being realised by all healthcare professionals, including physiotherapists, as being important for orthopaedic practice and research (Mehta and Grafton, 2014; Marshall et al., 2006).

Further to this, 'outcome research' is a process of collection of data, analysis of outcome data, and interpretation of the efficacy and effectiveness of patient treatment (Dobrzykowski, 1997). Outcome measurements may facilitate patient management decisions, assess clinician and organisation performance, and finally, clinical outcomes are advocated to provide evidence for the effectiveness of surgery and rehabilitation (Zelle et al., 2005). Overall, clinical outcomes are essential for the evaluation of patients and for the optimising of patient care, thus, outcome measurements are integral components in orthopaedic practice and research (Marshall et al., 2006; Swiontkowski et al., 1999). Within the subjective and/or objective assessment of ACL patients in routine physiotherapy evaluations, the use of reliable, validated and responsive standardised outcome measures have been repeatedly described as important in orthopaedic research and clinical practice, to assist in the optimisation of a patient recovery (Bent et al., 2009; Poolman et al., 2009; Reid et al., 2007).

Within the later phases of sports rehabilitation, where there is a focus on returning sporting-performers to competitive sports, outcome measures are directed at identifying an athlete's ability to physically tolerate sport-specific activity and prevent further injury when returning to competitive sports (Clark, 2001; Kong et al., 2012). The use of physical examination (also known as objective outcome measures) and the assessment of patients perceived dysfunction (known as subjective outcome measures) are both advocated to evaluate the effectiveness of therapeutic interventions, either in research and clinical practice. However, the implementation of these objective and subjective forms of outcome measures must be regularly administered, in order to monitor injured athlete progress over time (Irrgang and Lubowitz, 2008). Using outcome measures as an assessment of change, for example, following an operation or from assessing a patient over a period of time, requires a minimum of two separate time-points of assessment from which information needs to be collected; the magnitude of change that has been observed can represent the effect of a certain treatment. Within a research setting, it is very important that each of the outcome measures to be administered must be under conditions which are as similar as possible. With regards to the utility of outcome concerned with the validity, reliability, appropriateness and accuracy of outcome measures, only when having outcome measures deployed systematically and equally with adequate standardisation is any variability sufficiently controlled to enable valid conclusions to be drawn (Beard, Knezevic, Al-Ali, Dawson, and Price, 2010). Accurate outcomes assessment is one of the fundamental aspects of any reliable research (Zelle et al., 2005).

Outcome measures are, generally, divided into two broad categories and are characterised by their method of data acquisition as either a 'Patient-Based Outcome Measure' (P-BOM) or a 'Clinician-Based Outcome Measure' (C-BOM). In general, these two types of outcomes are also reported as either 'subjective' or 'objective' measurements, respectively (Hoeymans et al., 1996; Bent et al., 2009). Objective measurements may involve judgements or measurements conducted by a clinician on clinical or mechanical findings such as radiological changes, range of movement or measurements from joint laxity tests. Objective measurements are considered to generate "harder" information and, quite often, involve a higher-level of collected data (such as ratio, interval, and ordinal data). Likewise, the term 'subjective' is, generally, applied to evidence obtained about current health status based upon patients' own perceptions and, usually, involves standardised questionnaires.

2.4.1a - Patient-Based Outcome Measures

Patient-Based Outcome Measures (P-BOMs) will question the patient's opinion on an inventory of items; P-BOM is a term referring to the array of questionnaires, interview schedules, and other related methods of assessing health, illness and benefits of healthcare interventions from the patient's perspective (Collins et al., 2011; Fitzpatrick et al., 1998). Therefore, P-BOMs are subjectively assessing an individual's perceived dysfunction or disability (Reiman and Manske, 2011). P-BOMs can be categorised as being general/generic, disease-specific, population-specific, or site/region-specific outcome measures (Snyder et al., 2008; Garratt et al., 2004). However, P-

BOMs can be further divided into dimension-specific, summary items, utility-based, and patient-specific or individualised outcome measures (Fitzpatrick et al., 1998).

General/generic P-BOMs are used to evaluate outcomes such as Health-Related Quality of Life (HRQOL), while disease-specific measures are intended to measure specific aspects of HRQOL that focus on a specific injury (i.e., ACL tear or fracture), disease (i.e., osteoarthritis), anatomic area (i.e., knee), or targeted to a specific-population (i.e., athlete) (Guyatt et al., 1993; Patrick and Deyo, 1993). Site/region-specific P-BOMs contain sub-scales that are practically relevant to a patient group experiencing a particular treatment for a particular region (Fitzpatrick et al., 1998). It is suggested that the specificity of region- and disease-specific measures to an area or condition make these P-BOMs more responsive to smaller and more meaningful changes over time (Swiontkowski et al., 1999).

More recently, patient-specific or individualised patient-reported outcome measures have been recognised as another method of patient-assessment (Dekker and Dallmeijer, Lankhorst, 2005; Donnelly and Carswell, 2002). Individualised outcome measurement refers to those assessments in which the problem areas perceived are measured specifically for each individual patient's needs, and this can be either established by the patient or the clinician at the time of construction (Khorsan et al., 2008). For example, the patient constructing an individualised questionnaire is allowed to select his or her own issues, domains or concerns as to what outcomes have personally been affected since the time of injury (Fitzpatrick et al., 1998), and consequently, the construction of this method of assessment has not been defined to predetermined questions without imposing any standardised list of potential answers (Fitzpatrick et al., 1998; Ruta and Garratt, 1994). To date, no comprehensive review or systematic evaluation of individualised outcomes has yet been published for ACL-related outcome assessment and this warrants further investigation (Horn et al., 2012).

2.4.1b - Clinician-Based Outcome Measures

An objective measurement, as conducted generally by a clinician by often collecting data on the assessment of injury or illness. In this context, a physical measure objectively tests a patient to perform a specific task that is evaluated in a standardised manner using predetermined criteria, such as counting repetitions performed, or the time it takes to complete a task under the supervision of a physiotherapist (Guralnik et al., 1989). Generally, this method of assessment determines the level of functional impairment (Reiman and Manske, 2011). These objective and physical examinations can include hop, leap and jump performance tests, linear sprints, and agility tests measured by time or distance (Narducci et al., 2011), Range of Motion (ROM) examination using goniometry, thigh girth circumference measurements, and the use of knee laxity measures consisting of manual ligament tests (i.e., Anterior Drawer test and Lachman Test), to more quantitative methods of assessments using arthrometry (Shaw et al., 2005).

In addition to this, more sophisticated physiological indices of neuro-musculoskeletal performance measures are now implemented by clinicians and researchers alike, in assessing and monitoring both strength capability using isokinetic dynamometry and the assessment of proprioceptive deficits following injury (Pua et al., 2008; Fitzgerald et al., 2001; Gleeson et al., 1996; Gleeson and Mercer, 1996; Gleeson et al., 2002; Minshull et al., 2007). Although, the use of isokinetic dynamometry, arthrometry and proprioceptive testing equipment is expensive and they not always available within contemporary clinical practice (Gleeson et al., 2008; Doyle et al., 1998), their inclusion might allow an understanding of neuro-musculoskeletal and sensorimotor performance capabilities of patients during recovery and rehabilitation following ACLR surgery (Gleeson et al., 1996; Gleeson and Mercer, 1996; Gleeson et al., 2002; Minshull et al., 2007). More recently, the inclusion of neuro-musculoskeletal performance indices has been reported to provide further objective measures to inform decisions regarding recovery and return of athletes to sports (Angelozzi et al., 2012).

While the use of outcome measurements are advocated to evaluate the effectiveness of therapeutic interventions either in research or clinical practice, the implementation of objective and subjective forms of outcome measures must be regularly administered, in order to monitor injured athlete progress over time (Irrgang and Lubowitz, 2008) and, thus, provides an Evidence-based practice to assess, evaluate and justify clinical decision-making during the ACL rehabilitation process (Bradbury et al., 2013). However, there is an abundance of outcome measures used in clinical practice for rehabilitation of adults with musculoskeletal conditions of the knee (Garratt et al., 2004).

In this respect, there is an ongoing debate regarding the validity of C-BOMs and P-BOMs to assess patient function within ACL injury (Sernert et al., 1999; Neeb et al., 1997; Bent et al., 2009). However, the underlying principle is that functional status and Quality of Life (QoL) can be better described by the patients themselves, rather than by clinical practitioners (Vander-Zee et al., 1996). This has led to a considerable number of self-report instruments, questionnaires and rating scales being designed to measure the perspective of the patient (Wang et al., 2010; Garrat et al., 2004). Considering the large number of P-BOMs (Wang et al., 2010; Garratt et al., 2004) and C-BOMs (Narducci et al., 2011) currently deployed in clinical practice by clinicians and researchers to assess patients' outcomes, a recurring challenge is which P-BOM and C-BOM outcomes should be used (Bent et al., 2009).

A P-BOM is a term referring to the array of questionnaires, interview schedules, and other related methods of assessing health, illness and benefits of health care interventions from the patient's perspective (Collins et al., 2011; Fitzpatrick et al., 1998). Therefore, P-BOMs are subjectively assessing an individual's perceived dysfunction or disability (Reiman and Manske, 2011). P-BOMs can be categorised as being General/Generic, Disease-Specific, Population-

Specific, or Site/Region-Specific outcome measures (Snyder et al., 2008; Garratt et al., 2004). In addition, P-BOMs can be further divided into Dimension-Specific, summary items, Utility-Based, and Patient-specific or individualised outcome measures (Fitzpatrick et al., 1998).

General/generic P-BOMs are used to evaluate outcomes, such as Health-Related Quality of Life (HRQOL), while Disease-Specific measures are intended to measure specific aspects of HRQOL that focus on a specific injury (i.e., ligament tear or fracture), disease (i.e., osteoarthritis), anatomic area (i.e., knee), or targeted to a specific-population (i.e., athlete) (Guyatt et al., 1993). Site/Region-Specific P-BOMs contain sub-scales that are practically relevant to a patient group experiencing a particular treatment for a particular region (Fitzpatrick et al., 1998). It is suggested that the specificity of region- and disease-specific measures to an area or condition make these P-BOMs more responsive to smaller and more meaningful changes over time (Swiontkowski et al., 1999; Guyatt et al., 1993).

More recently, Patient-Specific or individualised patient-reported outcome measures have been recently recognised for another method of patient-assessment (Dekker et al., 2005; Donnelly and Carswell, 2002). Individualised outcome measurement refers to those assessments in which the problem areas perceived are measured specifically for each individual patient's needs, and this can be either established by the patient or the clinician at the time of construction (Khorsan et al., 2008). For example, the patient constructing an individualised questionnaire is allowed to select his or her own issues, domains or concerns as to what outcomes have personally been affected since the time of injury (Fitzpatrick et al., 1998), and consequently, the construction of this method of assessment has not been defined to predetermined questions without imposing any standardised list of potential answers (Fitzpatrick et al., 1998; Ruta and Garratt, 1994). To date, no comprehensive review or systematic evaluation of individualised outcomes has yet been published for ACL related outcome assessment and warrants further investigation (Horn et al., 2012).

The use of C-BOMs, similarly known as clinician-rated or often referred to as 'objective' outcome measures (Valovich McLeod et al., 2008), are primarily employed to facilitate decision-making regarding intervention choices by clinicians for their patients (Micherner, 2011). C-BOMs include a number of different methods of assessment that will measure functional and physical ability from the perspective of the clinician (Suk et al., 2005). C-BOMs are, usually, in the form of an objective measurement or test performed either by the clinician themselves (i.e., physiotherapist measuring range of motion using goniometry of the knee joint, or performing a Lachman Test for measuring anterior cruciate ligament integrity), or by the patient performing a functional or performance-based test; for example, a Single-Leg Hop for distance test measured over time or distance (Gulick and Yoder, 2002; Reid et al., 2007).

Generally, this performance-based outcome measure objectively tests a patient while performing a specific task that is evaluated in a standardised manner using predetermined criteria, such as counting repetitions performed, or the time it takes to complete a task (Guralnik et al., 1989). Meanwhile, with clinicians observing this functional based-test provides an opportunity for clinicians to record this observed functional activity and to subsequently make an informed decision regarding the patient's progress in their performance (Binkley, 1999). C-BOMs are, generally, assessing the functional impairment related to the injury, disease or illness (Reiman and Manske, 2011). Most C-BOMs assess impairment; however, sometimes functional limitations are also in need of assessment. For example, assessing functional limitation is important, because patient goals should be directed toward improving function and disability, in contrast to overcoming impairments (Quinn and Gordon, 2003).

More sophisticated clinician-derived outcomes or performance measures have been used within clinical practice. Here, physiological indices of neuro-musculoskeletal performance measures are now implemented, by clinicians and researchers alike, in assessing and monitoring both strength capability using dynamometry and the assessment of proprioceptive deficits following injury (Pua et al., 2008; Fitzgerald et al., 2001; Gleeson et al., 1996; Gleeson and Mercer, 1996; Gleeson et al., 2002; Minshull et al., 2007). Although the use of dynamometry, arthrometry and proprioceptive testing equipment is expensive and not always available within contemporary clinical practice (Gleeson et al., 2008; Doyle et al., 1998), their inclusion might allow an understanding of neuro-musculoskeletal and sensorimotor performance capabilities of patients during recovery and rehabilitation following ACLR surgery (Gleeson et al., 1996; Gleeson and Mercer, 1996; Gleeson et al., 2002; Minshull et al., 2007). More recently, the inclusion of neuro-musculoskeletal performance indices has been reported to provide further objective measures to inform decisions regarding recovery and return of athletes to sports (Angelozzi et al., 2012).

2.5 - Personal Construct Psychology and Personal Construct Enquiry Techniques

2.5.1 - Personal Construct Psychology

As previously discussed, the Personal Construct Psychology is a field of psychology that places the individual at its central focal point (Fisher and Savage, 1999). The Personal Construct Theory was based on the research of Dr. George Kelly in the context of his work as a clinical psychologist, which was developed around this premise. George Kelly initially defined his theory in two published volumes of work, entitled 'The Psychology of Personal Constructs' Volume One [entitled, Theory and Personality] and Volume Two [entitled, Clinical Diagnosis and Psychotherapy] (Kelly, 1955/1991b). The 'Role Repertory Test' was an elicitation enquiry tool that George Kelly developed and then discussed throughout his second volume, in regards to its clinical applications to explore an individual's personal constructs. Definitions of personal construct and constructs systems soon followed. The Repertory Grid technique, as it is formally known today, is an elicitation enquiry tool used to elicit and evaluate qualities of individuals' personal constructs

(Fransella et al., 2004). The Repertory Grid technique is reported to be the most widely known aspect of the work of George Kelly (Bell, 2003).

Kelly (1955/1991a) elaborated on the PCT within the book, Volume One, by discussing one of the fundamental key tenets of the personal construct psychology which was termed 'Constructive Alternativism'. Kelly suggested, rather than conforming to the concept of one unalterable reality, that individuals always have more than one way to interpret and give meaning to the world. Kelly (1955/1991a) contrasted constructive alternativism with the philosophical position that knowledge is advanced through the accumulation of facts and truths, later termed as Accumulative Fragmentalism. This theory states that 'all of our present interpretations of the universe are subject to revision or replacement' (Kelly, 1955, p. 15); therefore, and more simply, this theory of personality attempts to understand and explain the way in which individuals interpret and behave in the world. Here, Kelly (1995) believed that individuals attempted to understand the world around them by developing personal construct theories. The developed theories (and which were later known as constructs), would enable individuals to anticipate events in their lives and subsequently which can be revised based on their experiences of those events over time - what Kelly refers to as the Experience Corollary (Weston et al., 2010).

Kelly (1963) revisited the personal construct theory in a more accessible and user-friendly version entitled 'A Theory of Personality' in 1963. The PCT is, at times, referred to as Personality Theory. Unfortunately, George Kelly died in 1967 while working on his latest and third book in his series, discussing the PCT, however, the preface was only produced and published (Kelly, 1970). A selection of research papers by George Kelly have been collated into several books as a collection of George Kelly's work (Maher, 1969). All of the theories proposed by George Kelly (Kelly, 1955; Kelly, 1991a; Kelly, 1991b; Kelly, 1963) were central to one fundamental question for psychology, which becomes 'how do people develop, share, and use their personal theories?' (Fransella et al., 2004; p. 33).

A further elaboration of the PCT was presented by the explaining of the eleven corollaries that were named the 'Fundamental Postulate', this being the philosophical assumption of the PCT. Kelly described the following eleven Corollaries: Construction, Individuality, Organisation, Dichotomy, Sociality, Range, Experience, Modulation, Fragmentation, Commonality, Choice Corollaries, respectively (**TABLE 2**; p. 85**)**. The Fundamental Postulate stated, 'a person's processes are psychologically channelled by the ways in which he anticipates events (Kelly, 1991a, p. 46) and an individual 'anticipates events by construing their replications' of these events (Kelly, 1991a, p. 50). The corollaries were also developed to extend the theory and added more elaboration to how the theory impacts and can be used by other researcher and practitioners (Fisher and Savage, 1999). Principally, the eleven corollaries stipulate and describe the nature of construing; construing is the process term to represent the interpretive process, whereby, individuals seek to reveal meaning from the succession of events (i.e., elements) they experience by identifying recurring themes and their contrasts (i.e., previously noted as constructs).

Kelly attempted to explain in his theory the way in which individuals interpreted and behaved in the world, similarly believing that individuals acted as ‘scientists’. Thus, in order to understand their social surroundings, individuals react to the world and with events occurring within their life, whereby, those individuals would continuously construct, amend and reform personal theories and their own assumptions. More simply, individuals build a model based upon their experiences that allows them to make predictions about their future behaviours or interactions (Bell, 2007).

George Kelly attempted to explore the personal construct system using the Repertory Grid technique by exploring the Fundamental Postulate. In that, Kelly states that a person’s processes are psychologically channelled by the ways in which the individual anticipates events. The word ‘way’ in the statement above is defined within the constructs used in the repertory grid, while the wording of ‘events’ are the elements similarly used within the Repertory Grid. The principal objective of the Repertory Grid involves the defining of a set of elements, eliciting a set of constructs that distinguish among these elements and, in turn, relate the elements to constructs (Fransella et al., 2004).

Within the repertory grid, methodology is deployed by a structured interview by formalising the interactions of the interviewer (or researcher) and the interviewee (the participant). The technique allows the users to explore the relations between elements and constructs. The basic construction of the repertory grid is conducted within a table with rows and columns forming the overall ‘matrix’. In the standard elicitation procedure, the elements are determined first (listed in the columns of the grid matrix), and the constructs are elicited from the person who is being interviewed, and by providing distinctions among these elements, these identified constructs are placed within the rows of the matrix.

TABLE 2 - An overview of Personal Construct Theory outlining of the eleven corollaries edited and adapted from Kelly (1955/1991a) with interpretation from Gucciardi and Gordon (2009a).

Corollary	Direct quote from Kelly (1955/1991a)	Interpretation of the corollary
Construction	A person anticipates events by construing their replications (p.50/35).	We identify recurring or consistent themes, which enable us to anticipate their replications and recognize them when they do occur, by distinguishing between those things that are similar and those that are not.
Individuality	Persons differ from each other in their construction of events (p.55/38).	Each person is different not because they experience different events but because of the idiosyncratic and unique manner in which they make sense of their experiences.
Organization	Each person characteristically evolves, for his [sic] convenience in anticipating events, a construction system embracing ordinal relationships between constructs (p.56/39).	People develop a hierarchical system of interrelated constructs where some constructs are more important (superordinate) than others (subordinate) in an attempt to make their world manageable.
Dichotomy	A person's construct system is composed of a finite number of dichotomous constructs (p. 59/41).	People store their meaning-making experiences in the form of bipolar constructs, which guide how an individual thinks, feels, and behaves.
Choice	A person chooses for himself [sic] that alternative in a dichotomized construct through which he [sic] anticipates the greatest possibility for elaboration of his [sic] system (p.64/45).	Rather than being passive or reactive, at some level of awareness people choose a preferred pole of a construct that seems most useful for predicting future events.
Range	A construct is convenient for the anticipation of a finite range of events only (p.68/48).	Each personal construct has both a focus and range of convenience (i.e., area of maximum usefulness) in which it can be most applicable and others where it will not; that is, no construct is useful for everything.

Corollary	Direct quote from Kelly (1955/1991a)	Interpretation of the corollary
Experience	A person's construction system varies as he [sic] successively construes the replication of events (p.72/50).	Personal construct systems undergo a progressive evolution as people continually attempt to make sense of their world in which some personal constructs are validated and retained while those that are not validated are revised.
Modulation	The variation in a person's construction system is limited by the permeability of the constructs within whose ranges of convenience the variants lie (p.77/54).	Permeable constructs are more useful in making sense of novel occurrences or events, while those that are impermeable are impenetrable and not open to change.
Fragmentation	A person may successively employ a variety of constructions subsystems which are inferentially incompatible with each other (p.83/58).	People's construct systems do not always have to be logically related because constructs within an individual's system may appear incompatible or inconsistent with each other, as far as their superordinate constructs are permeable enough to tolerate these inconsistencies.
Commonality	The extent that one person employs a construction of experience which is similar to that employed by another, his [sic] processes are psychologically similar to those of the other person (p.90/63).	Despite personal construct systems being idiosyncratic and unique, individuals may share similarities in the ways in which they make sense of events.
Sociality	To the extent that one person construes the construction process of another he [sic] may play a role in a social process involving the other person (p.95/66).	This corollary is concerned with interpersonal understanding and interaction by which people go beyond simple observation of another's behaviour and interpret what that behaviour means to them; that is, construing another person's construction of events.

An important and most basic concern for the use of personal constructs in the Repertory Grid is whether the constructs should be elicited from the interviewee or supplied by the interviewer. From the perspective of the PCT, the construct should be elicited from the interviewee since they are personal constructs and meaningful to the individual only. Moreover, it could be expected that supplied constructs might be less meaningful. However, research focussing on supplied versus elicited constructs do produce similar outcomes. For example, Adams-Webber (1970) reported that individuals preferred to use their own constructs and that it made no difference in outcomes with differing methods. Similarly, it was reported that preferences to use own constructs, rather than constructions being supplied, were significantly more accurate (Adams-Webber, 1998). The issue of supplied versus elicited constructs is dependent on the context in which the Repertory Grid is being deployed (Fransella et al., 2004).

Kelly introduced a standardised procedure for obtaining items (constructs) for both individuals and a group setting. The elicitation procedures suggested six triadic methods of elicitation, the most common being referred to as the 'minimum context' form. In this procedure, three elements at a time would be examined (known as triads) and for each set one is asked to consider some important way in which the two elements are considered to be alike (this is described as the emergent pole of the construct) and, thereby, different from the third element (this opposite pole of the construct is known as the contrast pole). This process is repeated with an additional three different elements until all items (constructs) have been elicited. The finished product can be analysed to produce a 'construct map' of those elements which are individualised to each individual's perceived needs. It is interesting to note, that this bipolar distinction is in accordance with the dichotomy corollary.

In this grid format, the interviewer can understand those constructs that the interviewee considers to be personally meaningful for some particular event (i.e., the Olympics), context (i.e., competition or training), or set of objects (i.e., people). After the completion of the above process, the interviewee then rates accordingly each element against each construct previously identified. A numerical and ordinal rating scale depends on its application and complexity of analysis, on a scale of one to five or one to nine, respectively. As an example, a rating of one would indicate that the phrase in the left-hand column most accurately describes an element; conversely, a rating of five (or nine) would indicate that the phrase in the right-hand column most accurately describes the element.

There have been a number of other personal construct elicitation and enquiry techniques used within these fields to understand human behaviour, such Laddering, Pyramiding, ABC model, and Self-characterisation techniques. As yet, the application of the Personal Construct Psychology has yet to feature strongly in sport and exercise settings (Gucciardi and Gordon, 2009a; Gucciardi and Gordon, 2009b). Although not frequently reported in the literature, researchers and practitioners have utilised several personal construct psychology enquiry techniques to explore an individual's personal construct system, whereby, the Performance Profile and Multisource/360-Degree Feedback are two elaborations of Personal Construct Psychology that have been utilised in sport and exercise settings (Walker and Winter, 2007; Weston et al., 2013).

The Repertory Grid has demonstrated to practitioners and researchers alike that the technique has a means to identify personal constructs. However, it does not establish the positioning of each construct with an importance rating or the positioning of that construct within the individual's overall construct system. Therefore, it is unknown what importance an individual places on each identified construct within their own construct system. Another personal construct enquiry technique, referred to as the Laddering technique, and has been proposed to obtain such information (Gucciardi and Gordon, 2009a).

Developed by Hindle (1965), the laddering interview allows the researcher or practitioner to gather information from the interviewee's perspective regarding his or her own personal construct system, and allows the interviewer to understand how the subordinate constructs relate to superordinate constructs (Neimeyer, Anderson, and Stockton, 2001). Therefore, the laddering process enables the individual to identify the importance of each construct within their own construct system. This technique has been reported to be flexible in its application, in that it can be adopted at any time within a sporting session by the practitioners. However, this method of enquiry requires a particularly high level of skill in order to be conducted correctly and is deceptively simple to use (Gucciardi and Gordon, 2009a). However, the laddering technique has been reported to provide little information and understanding how identified constructs relate to the elements within their range of convenience. More importantly, the laddering technique is primarily used to understand how constructs within a personal construct system interrelate an individual's organisation rather than content (Gucciardi and Gordon, 2009a).

Nevertheless, depending on which personal construct elicitation and enquiry techniques are used, the outcome of using such techniques are particularly useful in communication between practitioners and their patients. The Multi-source and 360-Degree feedback techniques have been reported to offer practitioners a means to understand individual's viewpoints while, effectively, they offer initial communication and structure in design. Here, both of these techniques enable practitioners to understand an individual's strengths and weaknesses within aspects of professional development (Garbett, Hardy, Manley, Titchen, and Mccormack, 2007).

Whereas, the Performance Profile has been widely reported as another method of personal construct enquiry within a sport and exercise setting to understand the perspective of an athlete (Weston, 2005; Weston et al., 2013). The Performance Profile was originally developed by Dr. Richard Butler in 1989. Butler (1989) sought to adapt the Repertory Grid technique by mapping the athlete's personal construct system onto a Performance Profile (Butler and Hardy, 1992).

Principally, the Performance Profile is an extension of the Repertory Grid technique which is also extrinsically linked and developed from Kelly's (1955) PCT (Gucciardi and Gordon, 2009b). Using this profiling technique with athletes has shown a way of revealing gaps or areas for improvement and maintenance, as identified by both the athlete and their coaches, while providing a tool that can additionally be used to monitor athletes' and coaches' capabilities throughout a training programme.

However, it has been suggested that the Performance Profile does not incorporate several key aspects of the personal construct theory into the design of the Performance Profile and, as such, may not be a true understanding of an athlete's perspective. A revised and extended version of the performance profiling procedure has now recently been developed (Gucciardi and Gordon, 2009b). It is designed to attempt to understand all the key tenets of the Personal Construct Psychology approach (within which the authors argue that the traditional Performance Profile is not fully incorporated) and, thus, attempts to understand the true perspective of an athlete (Gucciardi and Gordon, 2009b). One example of improvement is where the revised and extended profile may enhance an understanding of an athlete's perspective by allowing athletes to generate a bi-polar personal construct would be more in-line with understanding an individual's comprehension of constructs, as opposed to just one emergent pole, as seen within Butler and Hardy's (1992) profiling technique. Nevertheless, Butler and Hardy's (1992) Performance Profile has been suggested to only incorporate four of these corollaries (Individuality, Commonality, Sociality and Organisation). Unfortunately, the remaining seven corollaries (Construction, Choice, Modulation, Experience, Dichotomy, Range and Fragmentation) are not used consistently in Butler and Hardy's (1992) Performance Profile. Therefore, it is argued that the Performance Profile does not fully incorporate the personal construct theory, because of missing key tenets to understanding the true perspective of an athlete (Gucciardi and Gordon, 2009a; Gucciardi and Gordon, 2009b).

Butler (1989, 1992) sought to adapt the Repertory Grid technique by mapping the athlete's corollaries of the personal construct system onto the Performance Profile, such as that presented in **FIGURE 3** (p. 56) and/or in **FIGURE 7** (next page). In contrast to the Repertory Grid, the Performance Profile has a user-friendly presentation, without the correlational and mathematical analyses required, that poses a problem for the sport-psychologist (Doyle et al., 1998). The Performance Profile within this representation allows both the athlete and management team to review the displayed information easily, which can be interpreted visually in order to understand the athlete's self-perceived strengths and weaknesses that have been identified as areas of improvement, necessary for enhancing performance (Butler et al., 1993).

The transference of the Repertory Grid into a more simplistic arrangement, of that presented with the Performance Profile as developed by Butler and Hardy (1992), still encompasses the basic components of the Repertory Grid methodology that being the elicited constructs on the perimeter and ratings of these constructs, with the advantages of the Performance Profile as previously discussed.

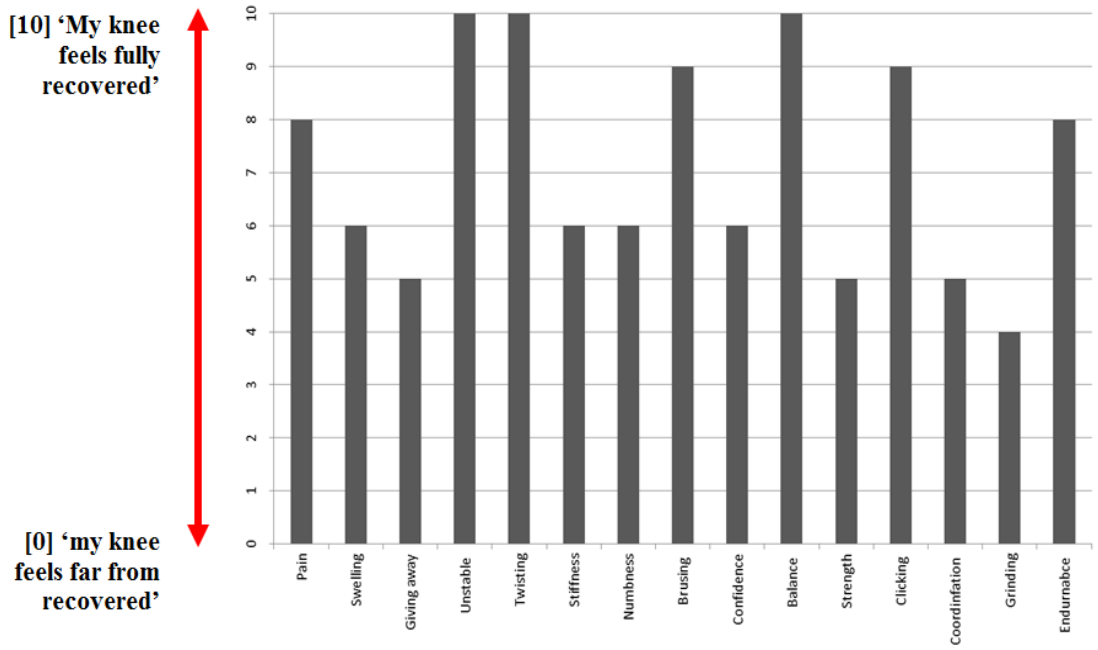

FIGURE 7 - Completed Performance Profile in a tabular design with the qualities the participant perceives to be in need of rehabilitation and improvement displayed around the perimeter of the profile for the injured limbs (adapted from Weston et al., 2013, and edited with clinical data obtained from this thesis).

2.5.2 - The origins and development of the Performance Profile

The Performance Profile was developed over several years by Dr. Richard Butler, and was first introduced to Great Britain's Olympic Boxing Team prior to the 1988 Seoul Olympics (Butler, 1989). Butler (1989) originally proposed that in order to succeed in any psychological intervention programme, the sport psychology team must understand the individual's perceptions. In the original instance, this was the boxer's perception of themselves in terms of their current performance, and the attributes required for optimal performance of an elite boxer. Conversely, Butler (1989) also sought to understand, not only the perspective of the athlete in terms of what the athlete considered important, but the importance and consideration of the coaches' perspectives of the athlete's performance and areas in need of improvement.

From June 1988, as part of a psychological intervention programme using 'iconics' as a form of imagery to optimise performance, Dr. Butler began interviewing eight Great British Olympic boxers in preparation for the 1988 Seoul Olympics (Butler, 1989). In order to understand each athlete, an initial interview was conducted that questioned each athlete individually about their strengths, weaknesses, areas of desired improvements and attributes and qualities of admired boxers. A comprehensive and sizeable list of attributes and qualities was collated from this. Subsequently, in a group setting, the eight boxers agreed upon a final list of twenty qualities and attributes that an elite boxer would possess, i.e., determination, fitness and a strong punch. Each athlete then rated themselves, using a 1 to 7 scale on how they perceived themselves in terms of the listed attributes and qualities, and also stated how they would wish to be. This process allowed Dr. Butler, the team's sport-psychologist, to understand each boxer's self-perceived strengths and weaknesses, and moreover, an examination of the discrepancy between the 'perceived self' and the 'ideal self' which would indicate areas in need of improvement and desired change. Butler (1989) then went on to use iconics as a form of imagery to enhance the development of skills in the areas of desired change identified from the self-perception maps.

As the first published account exploring the basic concept of what is now formally known as the Performance Profile, Butler (1989) gave only a brief account and rationale for his work with the Great British Olympic boxing team. The portrayal of his experiences of consulting with the Great British Olympic boxing team gave only a vague description of the methodology used in his consultations, and was limited in its descriptive overall account. His reasoning was limited in its theoretical origins and, therefore, was largely anecdotal.

However, following several years of applying the Performance Profile to the Great British Olympic boxing team and reflecting on its application, Dr. Richard Butler and Dr. Lew Hardy in 1992, produced a more updated, detailed description of their accounts of the Performance Profile directed towards the research community, publishing an article entitled 'The Performance Profile: Theory and Application' (Butler and Hardy, 1992). Butler and Hardy (1992) were dissatisfied with traditional sport psychology consultancy approaches such as those described by Boutcher and Rotella (1987) and Thomas (1990), which encouraged little involvement by the athlete in the decision-making process regarding the initial performance assessment phase of athletes in preparation for elite competitive events (Butler and Hardy, 1992). In addition to this, the central premise of using the Performance Profile with athletes, was that using Performance Profiles may heighten the self-awareness of the athlete, in terms of evaluating his or her strengths and weaknesses, and may also allow the athlete to understand the perceived areas in need of improvement in relation to his or her performance (Butler et al., 1993). For the athlete and the coaching team, the completed Performance Profile assists in the understanding of how the athlete is construing his or her own preparation and performance within his or her chosen sporting event.

Subsequently, following the understanding of the athlete's perspective from the completed individualised Performance Profile and, in some instances, the coaching team's concomitant ratings of the athletes identified attributes or characteristics, the coaching team (and sometimes with the assistance of a sport-psychologist) aided, in turn, developing a physical and psychological training intervention programme (Jones, 1993). Essentially, the Performance Profiling approach allows the athlete to provide feedback of his or her opinions and of their perceptions of their own capabilities of performance, and to plot an 'ideal rating' on each of the profiles qualities and characteristics. Hence, this fundamentally allows the athlete to self-set goals in terms of what is needed to be improved upon (Butler et al., 1993). At the same instance, Performance Profiling has evolved as a method of increasing coach awareness, while acknowledging the importance of the athlete's perspective (Butler and Hardy, 1992). However, the athlete and coaching team may view training and goals differently. In turn, the coaching team may not accommodate the perceived needs of the athlete, resulting in frustration by the athlete and 'switching off' to his or her training and conditioning programme (Weston et al., 2013). In addition, areas resistant to change, in particular, areas that the athletes perceive not to be as important as compared to the views and opinions of the coaching team could, therefore, have implications for the coaching team who may become increasingly frustrated with the athlete's lack of continual effort for development in these particular areas (Butler and Hardy, 1992). This conflict in a difference of opinion and the strategies to overcome such issues using the Performance Profile is also discussed further on within this literature review.

Butler and Hardy (1992) proposed a three-stage procedure, stage one and three of the performance profiling procedure being the same, for both the individualised athlete and for the athlete using the Performance Profile in a group/team interaction. However, in stage two, whereby the athletes are considering the qualities, which they perceived an elite performer in their chosen sport would possess, differs in its methodology. However, at the outset, to the completion of the Performance Profile, each participant should, in short, receive **(1 :)** an introduction of the idea and the intended purpose of the Performance Profile, and **(2 :)** an athlete is encouraged to consider what aspects of his or her performance are important to their chosen sport. Traditionally, a generic statement consists of asking either an individual athlete or athletes within a group, "What in your opinion are the qualities or characteristics of an elite athlete in your sport?" The statement proposed has since become a template from which a variety of alternative questions have been asked, and which have been adapted to suit consultancy demands (Weston, 2005).

Within a team/group setting, groups of athletes are initially asked to explore the statement above within smaller subdivided groups, typically based on position within a team; for example, in a soccer squad, whereby, athletes would be split into goalkeeper, defender, midfielder and attackers (Weston, 2005). After 5-10 minutes, the qualities or characteristics generated are discussed collectively in the original larger group. Following this, each athlete has the opportunity to construct and create his or her own individual Performance Profile using an inventory of items (constructs) previously discussed (choosing his or her own qualities or characteristics from this inventory) from the group at stage two of the Performance Profile procedure. Interestingly, one variation of this, is that athletes within the combined larger group cooperatively agree upon the qualities or characteristics that are possessed by an elite athlete in the sport in question. With this achieved, each athlete can rate his or her own self-perception of capabilities on each of the qualities or characteristics identified in his or her own Performance Profile, or on the agreed inventory list in the latter methodology presented.

Using the Performance Profile, the athlete and coaching team can work together to negotiate realistic agreed goals, that are both set by using the Performance Profile - being, firstly, determined by the athlete producing a 'now' rating on his or her own performance capabilities and, subsequently, a rating score of 'ideal or where I would like to be' on his or her performance profiling chart and, secondly, following a discussion with the athlete and the coaching team. The Performance Profiling methodology has been proposed to encourage the communication between the athlete and the coaching team (Dale and Wrisberg, 1996) and to further facilitate greater engagement and adherence to training conditioning programmes (Jones, 1993). The Performance Profile is inescapably an athlete-driven procedure and it, thus, sits comfortably with the empowering ideologies of many psychological training programmes (Butler et al., 1993).

A comprehensive overview of Butler and Hardy's (1992) procedure is presented below. The first stage of Butler and Hardy's (1992) Performance Profile was to examine how the athlete was currently feeling about his or her preparation for competition. This stage was achieved by providing examples of previously completed Performance Profiles to illustrate the type of qualities that have been identified previously, and provided the athlete with an illustrative example of the end product. It was also important to express that there was no right or wrong answer and that reflecting honestly on his or her performance would aid the design of a training programme tailored to the areas of weaknesses identified from the Performance Profile (Weston, 2005; Weston et al., 2013). The principal objective was to explore what the athlete considered important in their chosen sport. As Ravenette (1977) suggested, because an individual may operate at a low level of consciousness, using the Performance Profile may allow the athlete to improve his or her own self-awareness, and working with the coaching team could help formulate a training programme based on identified areas of perceived need, as the management team would then have an understanding of how the athlete is construing his or her preparation and performance (Butler et al., 1993).

The second stage of the process involved the athlete exploring the qualities they perceived an elite performer in their chosen sport would possess. When working with a team of athletes, this process would be achieved via a 'brain storming' session and would generally be completed in small groups, taking approximately 5 to 10 minutes to complete. Butler and Hardy (1992), when working with a team of athletes, asked each of the small groups to consider "what in your opinion are the qualities or characteristics of an elite athlete in your sport?" (Butler and Hardy, 1992). Here, were a broad a range of qualities to later share with the team as a whole. When working with an individual athlete, the same question could be asked; however, often assistance would sometimes be required to facilitate a range of qualities. In this construing process, one particular example of how this could be achieved would be by contrasting the qualities of two different performers and discussing how these different athletes cope within the same event. Similarly, in either an individual or team setting, the authors suggested that an elite performer from the same sport that the athlete or team held in high regard should be incorporated into these discussion sessions to further facilitate the elicitation process.

Each athlete was then asked to rate the identified qualities using a 0 to 10 scale. For further details of the methodological procedure, Butler and Hardy (1992) referred the reader to Butler (1991), where this was discussed further in a book chapter. This final stage was known as the assessment stage.

Further described in Butler's (1991) book chapter, the author begins with a similar description to the one described above. However, throughout that book chapter, Dr. Richard Butler provides additional advice on the implementation of the Performance Profile which has been developed from his experience with his consultations using this profiling technique. Following the introduction of the idea and the principle objectives of the Performance Profile, the Performance Profile was constructed by allowing athletes to see previously identified characteristics and qualities, and which have been mapped onto completed Performance Profile charts. A construction of a Performance Profile was again introduced, by asking the question to explore what constitutes an ideal performance, for example, 'What constitutes an ideal boxing performance and which boxers exemplified those qualities?' In addition to this, exploring the items (constructs) that the athletes perceived his or her role model would possess. Another means to facilitate this would be to ask the athlete to describe someone they know and to generate a list of strengths and weaknesses. This, in some instances, may be more appropriate to describe an 'ideal' performance, in addition, having the athlete to identify a previous best performance rating may allow a more realistic target for the athlete to seek to achieve.

It is suggested that the coaching team ask probing questions of the athlete in order to explore similarities and differences that other athletes may have. For example, to describe how one athlete maybe more superior to another athlete, or why two unsuccessful athletes were alike and two successful athletes were alike. Hemmings and Holder (2009) reported that this approach to identify the characteristics or qualities of an elite performer is slightly different to that previously conducted with athletes identifying items (constructs) in a group and 'brainstorming' ideas (Butler and Hardy, 1992; Butler et al., 1993). Moreover, as a fundamental premise of Kelly's (1955) PCT[27] suggests that each individual has their own unique items (constructs) and these help the individuals to guide the interpretation of information, then practitioners using the Performance Profile 'should seek to

[27] Personal Construct Theory (PCT).

identify the uniqueness of these qualities using an ideographic (within subject) approach' (Hemmings and Holder, 2009).

Essentially, athletes should try to attain at least twenty attributes to answer the proposed question. With this, no restriction should be stipulated and, if needed, more than one profile can be used to accommodate a wider range of items (constructs). Of the inventory of items (constructs) produced, it is important that the labels or descriptions used by the athlete are to use his or her own wording and terminologies. It is also important to note that items (constructs) are personal to the individual and in some situations may not be transferable to other athletes. To ensure a true understanding of the athlete's perspective, it is suggested that the coach or sport-psychologist understand 'what is meant' by each of the qualities identified. It may be useful for these meanings to be written down for future reference.

Further to the brief rating descriptions presented by Butler and Hardy (1992), Butler (1991) further describes a 10-point anchored scale, using a one to ten scale, with 0 (not at all) to 10 (very much so). In addition, Butler (1991) suggests that not too much time should be spent deliberating or analysing each rating of each construct, as this makes the rating more difficult. Within the rating scale, athletes should be encouraged to maximise the range of the scale within the Performance Profile chart. It is particularly important that the coach or the sport-psychologist does not devalue the qualities within the assessment stage of the athlete, if the athlete does not feel a construct is relevant. But, if the coaching team suggests one that may be appropriate to the athlete it may be helpful for the athlete to take the coaches perspective. This can be achieved by several techniques, one being via video analysis, and this technique may influence the athlete to reconsider a particular construct or particular aspect that is resistant to change.

Illustrated examples from Butler and Hardy (1992) provided the reader with four adaptations of the Performance Profile. Each example presented used the Performance Profile in a different way, in particular the rating methods by either the coach or the athlete. Adaptations of Butler and Hardy's (1992) procedures allowed the reader to further understand the athlete's perspective and allowed the coaching team a means to optimise a training programme based on the identified concerns of the athlete in question.

Firstly, an example of an individual Performance Profile was presented from an elite international weight-lifter in preparation for the 1990 World championships; this was constructed using the procedural stages, one and two (in Butler and Hardy, 1992). In a brain-storming session, each weightlifter was asked to consider what constitutes an elite performance in the event of weight lifting. The identified qualities and attributes of an elite performance were further categorised into physical, technical, attitudinal and psychological characteristics. The weight-lifter (in this example) selected items (constructs) from four of the categories that the athlete considered to be important. These items (constructs) were then mapped onto a concentric radar design Performance Profile chart. Each of the items (constructs) was rated using a 0 to 10 scale, ‘not at all’ to ‘very much’, respectively. A rating of ten was at the outer perimeter of the profile, whereby, descending numbers of ratings became progressively lower towards the centre of the Performance Profile chart. The weight-lifter rated himself on the Performance Profile and identified characteristics by shading areas to give a current self-perceived score, known as the ‘now’ rating. A second rating labelled ‘top performance’ was also identified. To produce this ‘top performance’ rating, the athlete was asked to consider one of his best performances within the past twelve months and to rate accordingly. In this configuration, the athlete and the coaching team, at a glance, could assess areas in which the athlete felt he needed to develop in order to perform at his best, by seeing a discrepancy between his ratings of his best performance and his ratings of his current self. The Performance Profile chart also easily identified areas that the weight-lifter considered ‘stable’, whereby, he had identified certain characteristics with the same ‘now’ and ‘top performance’ score. The discrepancy ratings between the ‘now’ score and the ‘top performance’ score identified areas in need of improvement, that the coaching team could develop further in a training programme to optimise the athlete’s performance.

A second presented example reported the technical performance of an amateur boxer in preparation for the 1988 Olympic Games. In addition to the above ‘now’ rating used in the weight lifting example, the boxer was additionally asked to identify an ‘ideal’ score of where the athlete would like to be. The discrepancy between the ‘now’ and ‘ideal’ rating would allow the coaching team to further understand the athlete in terms of his areas of desired change. In this example, following certain items (constructs), the athlete identified particularly important areas that needed to be developed (‘feints’, ‘switching tactics’, and ‘working inside’) and were, subsequently, prioritised by the coaching team. Within the Performance Profile, a low ‘ideal’ rating of the items (constructs) ‘switching attack’ (an ideal rating of 7) and ‘possessing a powerful punch’ (an ideal rating of 6), suggested that the boxer may be resistant to change in these particular areas, as he does not see them as that important to be developed, compared to other items (constructs). Therefore, this may have implications for the coaching team who may become increasingly frustrated with the boxer’s lack of continual effort for development in these particular areas.

A third example utilised repeated completions of the Performance Profile to monitor an athlete’s perceived progress towards his or her ideal performance prior to a competition. In this current example, a degree of perceived change was reported for a judo athlete in preparation for his competitive event. Performance Profiles were completed four and eight weeks prior to the competitive event using the same items (constructs). This information provided the coaching team and the athlete with a degree of progress achieved. Using the Performance Profile in this way may provide encouragement that training in preparation for the competitive event is progressing well, that the ‘ideal’ has been achieved. Conversely, it may indicate areas in which the performer perceives that little or no progress has been achieved, and further attention is still required.

Butler and Hardy (1992) further provided a fourth variation of the Performance Profile. This example described an amateur boxer and his coach, whereby, both the athlete and the coaches’ ratings were taken into account. In this case, the amateur boxer was preparing for the 1990 Commonwealth Games and completed the Performance Profile in order to examine his punching performance. The coach in this example also completed the Performance Profile and rated how he perceived the athlete’s punching performance to be. Areas in which the athlete and coach were in agreement, for example weaknesses such as the athletes’ absence of ‘rotation’ and not ‘hitting through the target’, may be contributing to a poorer performance, and meant that coaching was fundamentally driven by this agreement and was referred to by Butler and Hardy (1992) as ‘compatible notions of change’. Conversely, where there was a discrepancy between the coach and athlete’s ratings of items (constructs), the athlete and coach would identify different areas in need of improvement and, therefore, would create areas for the coach and athlete to discuss further in order to optimise performance.

Butler and Hardy (1992), in following these examples, suggested that it may be beneficial to explore if a functionally cohesive team have similar Performance Profiles to the individually described profiles noted above. A further recommendation for future research by the authors was to ensure that an athlete’s perception of a certain quality or construct corresponds with that of the coach or sport-psychology team. Both of these suggestions had yet to be empirically examined. However, Bryan (1999) within an unpublished Master of Science thesis entitled, ‘The Relationship of Team Performance Profiling and Cohesion’, investigated the relationship between team Performance Profiles and team cohesion.

Butler and Hardy (1992) suggest that the Performance Profile may be able to help the coaching team to understand their athletes in several ways, to determine **(1 :)** areas of perceived strengths; **(2 :)** areas of perceived need for improvement; **(3 :)** the athlete’s vision of what constitutes a top elite performance; **(4 :)** where the athlete might resist improvement; **(5 :)** monitoring the athletes progress over time; **(6 :)** discrepancy between how the athlete and coach view performance; **(7 :)** discrepancy in what the athlete and coach consider to be important in producing an elite performance, and **(8 :)** analysis of performance following a competitive event.

A major difference between Butler’s (1989) procedure and the procedures described by Butler and Hardy (1992), is that Butler and Hardy’s (1992) version used a definitive three-stage process to describe the procedure, allowing the method to be more easily replicated. In addition, the ordinal rating scales differed, in that the original 1989 description used a 0 to 7 rating scale compared to the 0 to 10 rating scale deployed in Butler and Hardy’s (1992) version. Gucciardi and Gordon (2009b) in their recent review of the Performance Profile suggested that an ordinal rating scale of 0 to 7 should be utilised when rating the qualities chosen by the athlete. Weston and colleagues (2013) reported that in the previous literature, other rating scales had been incorporated within numerous Performance Profiles of self-assessment procedures.

For example, Butler and Hardy (1989) utilised a one to seven scale, and then later revised their rating scale to a one to ten rating system (Butler and Hardy, 1992). It has also been highlighted that the key issue when implementing the rating of an individual's Performance Profile, is that the scale used is meaningful to the individual, whereby, the athlete (or the patient, in this case) has a good understanding of what constitutes a rating of one and what constitutes a rating of ten, and that the rating scales used are clear and specific (Weston et al., 2013). Isaac and Michael (1995), in their handbook of research and evaluation stated that the number of rating positions for visual rating scales should be between 'five' and 'nine' with a total of 'seven' positions being the optimal number. It is not known which scale is preferred by the athlete or which rating scale has greater efficacy.

In summary, this more recent account by Butler and Hardy (1992) was, again, a descriptive case study approach, exploring the use of the Performance Profile while presenting examples from a range of Olympic sporting events such as weightlifting, boxing, figure skating and Judo. This updated version presented a more detailed methodological procedure for its application, with particular reference to its use in a team setting and to individual athletes; however, the reader was referred to another source (Butler, 1991) to understand the full procedure. Butler and Hardy (1992) provided some theoretical underpinning for the use of the Performance Profile in a sports setting, which were derived from the PCT, (Kelly, 1955) which was lacking in the original description by Butler (1989).

Butler and Hardy's (1992) published account of the Theory and Application of the Performance Profile provided several detailed sporting examples demonstrating that the Performance Profile has flexibility and versatility in its application. To date, Butler and Hardy's (1992) three stage method has been used as a template for its deployment in a myriad of applications. The fundamental premise of Butler and Hardy's (1992) version of the Performance Profile is its construction. In this instance, it allows the athlete to use his or her own chosen qualities (and own terminology) which has been categorised as being technical, tactical, physical and/or psychological qualities that he or she considers to be important for optimal performance of an elite athlete and, subsequently, rate themselves on these qualities. Therefore, the Performance Profile within a sport setting is athlete-centred and athlete specific (Butler and Hardy, 1992) and, more recently, has been described as a client centred, idiographic performance analysis tool (Weston et al., 2010; Weston et al., 2013).

Butler and Hardy (1992), in their introduction to the Performance Profile, stated that the theoretical underpinnings of the Performance Profile were 'selected' and embedded within the framework of the personal construct theory. The word 'selected' has been referenced numerous times throughout the literature, meaning that the Performance Profile uses some of the tenets of the PCT. These include the method of elicitation and labelling items (constructs), using an individual's own terminology.

In addition to PCT, Butler and Hardy (1992) highlighted the importance of Deci and Ryan's (1985) Cognitive Evaluation Theory (CET), in relation to an athlete's motivation (Deci and Ryan, 1985). It was stated that extremely controlled events are likely to weaken intrinsic motivation thus potentially leading to adherence issues during training (Bull, 1991). Simply, coaches controlled all of the performance assessments and training of athletes and this would restrain the athletes' perceptions of their own autonomy, and would likely to undermine athletes own intrinsic motivation towards his or her own training and performance (Deci and Ryan, 2002).

Within the CET, the fundamental postulate discusses the social and environmental factors or events (e.g., feedback, coach behaviour etc.) which may influence an athlete's motivation (Deci and Ryan, 2000). Here, the CET evaluates three essential mediators (or desires) that athletes attempt to satisfy (1: relatedness, 2: autonomy, and 3: perceived competence) in order to develop their own motivation. Specifically, the CET suggests that the social factors will reinforce athlete desires (i.e., relatedness etc.) and consequently will enable an increased heighten state of self-determination with positive behavioural responses. Within the Performance Profiling - allowing for athletes to discuss their own self-perceived needs - and construction of their individual profiles particularly in group brain-storming sessions with interaction with others would potentially enhance heighten perception of relatedness and autonomy, respectively. The adeptness of the Performance Profile to enable athletes to monitor their own progress could improve perceived competence as athletes see their profile ratings, increase over time, further supporting Performance Profiling in optimising motivation to athlete own training (Weston et al., 2012).

2.5.3 - Reliability, Validity, and Responsiveness of the Performance Profile

Several attempts have been made to objectively evaluate the Performance Profile in terms of the technique's validity and reliability with athletes (Palmer, Burwitz, Collins, Campbell, and Helm, 1996; Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Gleeson et al., 2005). The first attempt to assess the construct validity of the Performance Profile was conducted by Palmer et al. (1996). The principal aim of the study was to examine the validity of the Performance Profile, to consider its possible strengths and weaknesses and to make future recommendations for its use. Construct validity is defined as a test or a measurement tool that is established by demonstrating its ability to identify or measure the variables or constructs that it proposes to identify or measure (Clark-Carter, 2004).

Palmer et al. (1996) were the first to assess the construct validity of the Performance Profile. Participants were thirty-one international elite netball players, with the sample consisting of five senior players, fourteen under twenty-one players and twelve under eighteen players. Each player completed an individual Performance Profile in relation to their chosen sporting position within the game of netball, following the procedures outlined by Butler and Hardy (1992). Participants from the under twenty-one squad only, were asked for their opinions about the Performance Profile, how they construed the technique, and also about the procedural issues involved. The perceptions of these participants with regards to the usefulness of the Performance Profile indicated that ten of the participants (constituting 71%) reported that the Performance Profile was useful, with the most commonly reported usefulness being an increase in self-awareness and helping the players to understand and identify their strengths and weaknesses. This positive use of the Performance Profile, as reported by the participants in this study, had originally been proposed by Butler (1989) and Butler and Hardy (1992) and, therefore, supports their benefits of using the Performance Profile. Only four of the athletes reported that the implementation of the Performance Profile or applying it to actual play on the court was not relevant and was not helpful to them.

Construct validity was investigated by examining age-group differences on four psychological factors, anxiety management, concentration, motivation and self-confidence items (constructs), which were related to exceptional performance. ‘Priority scores’ for each of these items (constructs) were identified for each athlete from their Performance Profiles. However, the study presented here was only an abstract submitted as a conference communication to the Annual Conference of the British Association of Sport and Exercise Sciences (BASES), and full publication of the study was never reported. Therefore, the full details of the methods deployed are not discussed. Hence, it is not clear as to what the authors meant by ‘priority scores’, though it may be suggested that priority scoring was used so that participants could emphasise the relevance of some of the items (constructs). The authors reported that these results showed support from construct validity, because even the experiences of senior players were able to highlight the importance of concentration and motivation.

When comparing participants’ fitness self-rating scores with objective fitness assessment scores, results showed a significant relationship between the participants’ perceptions of ability on elevation ($r = -0.48$, $p< 0.05$), strength ($r = 0.67$, $p< 0.01$) and their actual ability as indicted by the fitness assessments. However, there were no significant relationships between participants’ perceptions of flexibility, speed and stamina and actual performance test scores ($r = 0.41$, $r = -0.39$, and $r = 0.34$, respectively, $p> 0.05$). These results again highlight the construct validity of the Performance Profile, as participants’ self-rating on some aspects of their fitness, as rated on their individual Performance Profiles, were correlated with actual fitness assessments and performance.

The authors highlighted that there were potential intra-subject differences for the speed construct due to the wide variability in the participant's interpretations of their own speed, and so practitioners should be aware of this. In addition, the construction of importance ratings also attracted problems where some participants rated some items (constructs) more importantly than they should have done for their playing position i.e., the goal shooter rated stamina as highly important despite the fact they have relatively low aerobic demands compared to other playing positions such as the centre position who has to cover most of the court and would have a higher aerobic demand. Therefore, the sport-physiologist could implement an inappropriate training programme based on the athletes' presented data in the Performance Profiles. They also reported that awareness is needed of the factors that may influence the elicitation of items (constructs) for a profile including the potential of the social desirability effect and bias for self-presentation. Future recommendations from the authors included a focus on minimising potential procedural problems by ensuring clear definition for all, comparing self-ratings with the coach's perceptions and objective data, and early and full discussion of any discrepancies which occur and not grouping individual data to implement a team-training programme.

In summary, this was the first attempt to assess the construct validity of the Performance Profile within a sporting context. The authors suggested that their study did support the construct validity of the Performance Profile. However, it is difficult to evaluate their findings, because their results were only presented in a conference abstract, and the study was never published in greater detail. The abstract has limited descriptions of the methodologies deployed and its subsequent rationale. The limited findings presented indicate that an interpretation of the results and findings are difficult, yet, support for the construct validity can be seen in some of the findings that were published within the abstract. However, there are some limitations to the study's methodology, such as an overall small sample size, and three age-groups with uneven sample sizes. In addition, the authors only gathered results from the under twenty-one players to examine the opinions about the Performance Profile, how the technique was construed, and the procedural issues involved in the technique. There was no rationale reported in the abstract as to why the other age-groups were not included in this part of the study.

From this first attempt to evaluate the construct validity of the Performance Profile conducted by Palmer and colleagues in 1996, there was clearly a need to scientifically evaluate the Performance Profile using a more robust methodological design than that described above. Similarly, in the same year, Doyle and Parfitt (1996) were also aiming to evaluate the Performance Profile by examining its predictive validity. Doyle and Parfitt (1996) aimed to assess the strength of the relationship between individual Performance Profile ratings of athletes, and athletic performance over a competitive season. It was hypothesised that predictive validity would be shown if areas of the perceived needs identified by the Performance Profile were predictive of actual performance. Participants were thirty-nine elite track and field athletes, with eighteen of the athletes competing at club level, and twenty-one elite athletes competing to an international standard.

The Performance Profile was introduced to the participants in a 'brainstorming' session as part of a group. Athletes were individually asked how each currently felt about his or her preparation for competition. Participants were divided into event-specific groups of four to six participants and asked to consider the question, "what, in your opinion, are the qualities or characteristics of an elite athlete in your event?" A collective discussion of the items (constructs) generated took place with all participants involved. In addition, with respect to items (constructs) generated from an elite athlete; a national coach and a researcher were included to develop a broad range of items (constructs). Each participant then completed an individualised Performance Profile to include ten to fifteen of the items (constructs) discussed. An 'ideal rating' for each of the items (constructs) was identified, using a ten-point scale. Demographic data were also collected, which included personal best performance times or measures. Subsequently, a meeting took place four days later where participants recorded dates of three track and field events in which they were competing during the competitive season. Participants completed their individualised Performance Profile immediately prior to each event where possible. Each participant was asked to evaluate where they would rate themselves on each construct at that present time. After each of the chosen competitive events, participants recorded their actual performance times or measures. Athletes and their coaches then also recorded a 'perception of performance' score for each of the events. Each participant profile was reduced to the ten most important items (constructs) for data analysis. A discrepancy score was calculated for each of the ten items (constructs) on each participant's Performance Profile by subtracting the score recorded immediately prior to each competitive event (the 'now' score) from the 'ideal rating' recorded for that construct. Doyle and Parfitt (1996) then used these ten discrepancy scores to create a 'mean profile discrepancy score' for use in analysis, so that each participant had one overall discrepancy score.

As there were no significant interactions observed in mean profile discrepancy scores between males and females and competitive levels across the three chosen completive events ($Fs_{(1, 36)} < 1.23$, $p > 0.27$), all scores were combined for all subsequent analysis. Results revealed that in the first and second chosen competitive events, the mean profile discrepancy scores were significantly correlated with the coaches' perceptions of performance scores [($r_{(21)} = -0.39$, $p < .05$); ($r_{(21)} = -.48$, $p < 0.01$), respectively]. In the third chosen competitive event, mean profile discrepancy scores were significantly related to the actual performance measures recorded, the athlete's perception of performance scores, and the coaches' perceptions of performance scores [($r_{(39)} = -0.56$, $p<0.01$); ($r_{(39)} = -0.59$, $p <0.01$); ($r_{(21)} = -0.87$, $p < 0.01$), respectively]. These results, thus indicated that a lower mean profile discrepancy score was associated with a higher performance score, and vice-versa.

Furthermore, linear regression results showed the mean profile discrepancy scores significantly predicted the coaches' perceptions of performance scores in the second chosen competitive event ($F_{(1,19)}= 5.67$, $p< 0.05$), accounting for 23% of the total variance. In the third chosen competitive event, the mean profile discrepancy scores significantly predicted 32% of the variance in actual performance ($F_{(1, 37)} = 17.31$, $p< 0.01$), 35% of the variance for athletes perception of performance ($F_{(1, 37)} = 19.93$, $p< 0.01$) and 75% of the variance for the coaches' perceptions of performance ($F_{(1, 19)} = 58.59$, $p< 0.01$).

A 'directional interpretation' of the correlations, therefore, indicated that a greater area of perceived need was associated with a greater decrement from optimal performance, thus, providing evidence for the predictive validity of the Performance Profile. The results also suggested that a continuous learning process may have occurred due to the progressively stronger relationships that developed across the time period, from the first through to the third chosen competitive event. Regression analyses also provided moderate support for the utility of the Performance Profile, because 23% of the coaches' perceptions of performance scores was explained by the mean profile discrepancy scores at the second chosen competitive event. However, 77% of the variance was unexplained by the association between these two variables. Nevertheless, at the third chosen competitive event, 73% of the total variance explained the association between the same 2 variables, that being the mean profile discrepancy scores and the coaches' perceptions of performance scores. This, therefore, suggested the possibility of a learning effect, and the potential for the Performance Profile to usefully predict performance.

In summary, mean profile discrepancy scores predicted the coaches' perceptions of performance scores with the greatest accuracy. This suggested a combined ability for the athlete to identify items (constructs) necessary for optimal performance, and any particular coach's ability to assess the athlete's performance on all the identified items (constructs) combined, thus allowing the coach to identify areas of improvement to enhance performance. The predictive strength of the relationship between Performance Profile ratings and the coaches' perceptions of performance scores indicated that the Performance Profile was, potentially, a useful coaching aid.

As with all research, this study was not without its limitations. It was difficult to discriminate between performance scores of the elite athletes, and so Doyle and Parfitt (1996) suggested that future research should increase the sensitivity of the Performance Profile scores and performance perception scores, and allow the use of values correct to one decimal place when working with elite athletes. Doyle and Parfitt (1996) also concluded that future studies evaluating the Performance Profile should incorporate a baseline profiling period prior to a performance evaluation in order to allow for the possibility of a learning effect which would allow greater accuracy of profiling.

Doyle and Parfitt (1996) reported on the measurement sensitivity of the Performance Profile, in that the Performance Profile may be unable to detect relatively small changes in the performances of elite athletes. Standard error scores of the prediction for the statistically significant regressions provided moderate support for the sensitivity of the prediction model to detect real changes in performance (standard error ranged from 1.35 to 1.88, with 95% confidence limits). Doyle and Parfitt (1996) provided an example of a high-jumper using the experimental procedure outlined in their study, where actual performance measures were recorded at 1.65, 1.60 and 1.63 metres across three competitive events. Based on the athlete's personal best performance of 1.70 metres, personal best performance percentages of 97%, 94% and 96%, respectively, (mean = 95.6%, standard deviation = 1.25) were determined.

Standardised scores across the three competitive events were calculated as 1.12, -1.28 and 0.32, with a range of 2.4. To effectively discriminate between the lowest and the highest of these three performances, a prediction model must have a standard error of the prediction of less than 2.4, with 95% confidence limits. The regression model predicting actual performance from profile ratings shows less predictor error than this range value of 2.4, whereby, the standard error was 1.83, with 95% confidence limits. Therefore, the prediction model is able to discriminate between the lowest and highest of the performances from the three competitive events. However, the criterion model has greater error than that necessary to discriminate meaningfully between the lowest and mid performance (range = 1.6), and between the mid and highest performance (range = 0.8) of the athlete.

In summary, Doyle and Parfitt (1996) reported that this level of measurement sensitivity for the Performance Profile may be unable to detect the relatively small changes in performance of elite athletes during a competitive season. Therefore, Doyle and Parfitt (1996) suggested that an increase in the sensitivity of the Performance Profile and the self-perception of performance scores might be needed, and advised that this be done by allowing values correct to one decimal place when using the Performance Profile in an elite athlete population. However, Doyle and Parfitt (1996) suggested that the Performance Profile may be a useful tool to use in non-elite athletes, or in elite athletes recovering from injury, where there would be greater changes in performance over time.

Developing further the future recommendations, as suggested in the earlier publication (Doyle and Parfitt, 1996), in order to further evaluate the utility of the Performance Profile, the authors utilised a rating scale of perceived need that permitted the athlete to respond in a more accurate manner using 100-point scale, as opposed to the 10-point scale previously used. In addition, participants undertook a period of practice in completing the Performance Profile to control for the potential intrusion of learning effects (Doyle and Parfitt, 1996). However, Doyle and Parfitt (1997) used participants from their previous study, and so the completion of three

Performance Profiles during that particular study acted as ‘periods of practice’ to control for the potential intrusion of practice effects.

The purpose of Doyle and Parfitt’s (1997) study was to assess the construct validity of the Performance Profile in elite track and field athletes. The study hypothesised that construct validity would be indicated if a greater area of perceived needs, identified by the Performance Profile, was reflected by a lower performance score. In opposition, construct validity would also be indicated by a smaller area of perceived need, identified by the Performance Profile, would be reflected by a higher performance score. Additionally, the items (constructs) rated most important to ideal performance on the profile of the participants would be more strongly correlated to actual performance than the items (constructs) rated least important to performance.

Participants were twelve elite track and field athletes who originally participated in the first study conducted by Doyle and Parfitt (1996) and so participants had previous experience in using the profile technique on at least 3 occasions during the competitive season. Inclusion criteria stipulated that participants were required to complete at least five training sessions each week for their event across the winter training period (October to January). Performance profiling was introduced to the participants in a ‘brainstorming’ session as part of a group, to clarify how each athlete perceived his or her preparation for performance. It was expressed, that the information provided by the Performance Profile could raise their own awareness and help identify and direct training in areas of perceived need with the help of the coaching team. To illustrate the basic procedures, examples of completed Performance Profile were shown to the participants. It was further explained that there were no right or wrong answers, but that the Performance Profile aims to show what the athlete considers to be important.

The participants were divided into groups of four to six individuals, depending on their sporting event and were asked to consider the question, ‘what in your opinion, are the qualities or characteristics of an elite athlete in your event?’ (Doyle and Parfitt, 1997, p. 414). Each group then shared the qualities they had generated with all the participants. A broader range of qualities and items (constructs) were further developed from the contributions of a respected elite athlete, a national coach and a researcher. Each participant then selected ten to fifteen qualities that he or she considered important for his or her own event and performance, in order to create their own individual Performance Profile. To identify areas of perceived need of improvement, an ideal rating for each of the items (constructs) was produced by asking them to consider a question, ‘ideally where would you like to be on each of the qualities you have listed?’ (Doyle and Parfitt, 1997, p. 414). A response scale ranging from ‘not at all like this’ (1) to ‘very much like this’ (10) was used.

In addition, an importance rating for each of the items (constructs) was also recorded, by considering the question, ‘how important are each of the qualities you have listed to the ideal athlete?’ (Doyle and Parfitt, 1997, p. 414). A response scale ranging from ‘not important at all’ (1) to 'of crucial importance' (10) was used. Participants could choose values correct to one decimal place (i.e., 1.2, 4.5, 8.6 etc.) for both the 'ideal' and 'importance' ratings. The items (constructs) and importance scores were mapped onto an individualised visual performance by the researcher. The exact labels generated by each participant were displayed around the perimeter of the Performance Profile chart. As part of the previous study (Doyle and Parfitt, 1996), athletes completed their Performance Profile immediately prior to their event in at least three separate competitions across the season. In addition, participants were asked to practice completing the Performance Profile immediately prior to three training sessions across the season. These practice sessions were used to account for the possibility of a learning effect on the accuracy of profiling (Doyle and Parfitt, 1996). When completing their Performance Profile before their event or training session each athlete was asked to evaluate 'where would you rate yourself at the present time on each of the qualities you have listed?' (Doyle and Parfitt, 1997, p. 415). Participant's responses ranged from 'could not be any worse' (1) to 'could not be any better' (10). Athletes were able to rate their responses correct to one decimal place in order to increase the accuracy of their ratings.

Participants completed their profile on five separate occasions throughout the initial winter training period to the peak of their competitive season. At week 4 (testing occasion 1) and week 14 (testing occasion 2) of the winter training period, a personal best previous time or distance for the chosen training session was recorded for each participant. Post training session, all participants recorded an actual performance time or measurement following their chosen sporting event. Participants and their coaches individually recorded a perception of performance score. A scale correct to one decimal place ranging from 'could not have done any worse' (1) to 'could not have done any better' (10) was used (Doyle and Parfitt, 1997, p. 417). The 3rd, 4th and 5th occasions (testing session, 3, 4 and 5, respectively) were three progressive competitions across the competitive season. Participants, again completed their profiles as close to the event as possible. A personal best competitive indoor measure or time was recorded for each participant. After each event, participants recorded the actual performance time or measure they achieved, and participants and their coaches again individually recorded a perception of performance score.

Each participant's Performance Profile was reduced to the ten most important items (constructs) for data analysis, determined by their importance ratings of the items (constructs). A discrepancy score was calculated for each construct on each participants Performance Profile by subtracting the score recorded immediately prior to competition (the 'now' score) from the 'ideal' score for that construct (Doyle and Parfitt, 1996), and this procedure was repeated for all five of the testing occasions.

As there were no significant interactions observed in mean profile discrepancy scores between males and females and across the five testing occasions ($F_{(1, 44)} = 3.21$, $p > 0.05$), all scores were combined for all subsequent analysis. A repeated measures analysis of variance indicated significant differences in mean profile discrepancy scores across the five testing occasions ($F_{(4,44)}$ = 15.70, $p < 0.05$). Post hoc Tukey tests suggested that the mean profile discrepancy scores were significantly higher on occasion one, compared to all other testing occasions. Additionally, mean profile discrepancy scores were significantly lower on occasion three, compared to occasion five. There was a significant decrease in mean profile discrepancy scores and a significant increase in actual performance scores from the winter training period to the competitive indoor season. These findings give support for the construct validity of the profiling technique as a significant reduction in perceived need was reflected by a significant increase in actual performance across the same time period.

An examination of performance scores showed a significant difference in actual performance scores across the five testing occasions ($F_{(4, 44)}$ = 26.30, $p < 0.05$). Post hoc Tukey tests suggested actual performance scores were significantly lower on testing occasion one, compared to all other testing occasions. Actual performance scores were significantly higher on testing occasion five, in comparison to testing occasions two and three. A repeated analysis of variance showed a significant difference in athlete perception of performance scores across the five testing occasions ($F_{(4, 44)}$ = 2.63, $p < 0.05$). Post-hoc Tukey tests suggested that athletes' perceptions of performance scores were significantly higher on testing occasion two, compared to testing occasion three. There were no significant differences in coach perception of performance scores in a separate repeated measures analysis of variance across the same five testing occasions ($F_{(4,44)}$ = 2.40, $p > 0.05$).

Linear trend analysis identified a significant linear trend in mean profile discrepancy scores across five testing occasions ($t_{(1)}$ = -5.94, $p < 0.05$). Separate trend analysis identified a significant linear trend for actual performance scores across the five occasions ($t_{(1)}$ =14.37, $p < 0.05$). A significant curvilinear trend was seen for athlete perception of performance scores across the five testing occasions ($t_{(1)}$ = 4.14, $p < 0.05$). However, no significant trends were identified for coach perception of performance scores across the five occasions. Further trend analysis identified a significant curvilinear trend for the mean profile discrepancy scores of the three items (constructs) each athlete classified as most important across the five testing occasions ($t_{(1)}$ = -8.55, $p < 0.05$). Separate analysis identified a significant linear trend for the mean profile discrepancy scores of the three items (constructs) each athlete classified as least important across the five testing occasions ($t_{(1)}$ = -5.46, $p < 0.05$). Over the five testing occasions trend analyses suggested changes in both Performance Profile, and actual performance scores were linear, with the most distinct difference between time occasions one and two for both profile and performance measures, where the greatest changes to performance would be expected. The linear patterning of actual performance scores across the five testing occasions was not mirrored by the athlete or coach perception of performance scores. Instead, athlete ratings of performance showed a curvilinear trend and no significant trends were observed for coach ratings of performance, therefore, providing no support for construct validity of the Performance Profile. Linear reduction in areas of perceived need was not mirrored by the expected linear increase in athlete/coach ratings of performance, therefore, suggesting some discrepancy between the athletes' ability to rate their performance compared to actual performance scores on some occasions.

Product moment correlation coefficients for mean profile discrepancy scores of the three most important items (constructs) and actual performances across the five testing occasions, and the three least important items (constructs) and actual performances across the five testing occasions were not significant. Therefore, the results did not support the hypothesis, indicating no strong relationship between the most important items (constructs) and performance compared to the least important items (constructs) and performance, thus indicating no support for the construct validity of the Performance Profile. The participants' greatest perceived needs (the three most important items (constructs) identified by each athlete) showed a greater and more rapid reduction across the five testing occasions, compared to the three least perceived needs (the three least important items (constructs), as identified by each athlete). This indicated a greater responsiveness and sensitivity in the three most important items (constructs), providing some support for construct validity. It was expected that the three most important items (constructs) would have a stronger relationship with performance than the three least important items (constructs). However, the three most important and three least important items (constructs) were only weakly correlated with performance.

In summary, this study represents the second attempt to address the construct validity of the Performance Profile. Palmer et al., (1996) suggested that their study did support the construct validity of the Performance Profile. However, it is difficult to evaluate their findings, because their results were only presented in a conference abstract, and the study was never published in greater detail. Further, this second attempt by Doyle and Parfitt (1997) suggests that the Performance Profile should be used cautiously. Results from Doyle and Parfitt (1997) showed some support for the construct validity of the Performance Profile, because an increase in actual performance was reflected by concomitant decrease in Performance Profile areas of perceived needs across the five testing occasions. However, the most important items (constructs) of the Performance Profile were more sensitive and responsive to change at certain times of the testing period. As suggested by Doyle and Parfitt (1996), and as indicated by the present study, it is unlikely that the Performance Profile has sufficient measurement sensitivity associated with elite athletes, whereby, relatively small changes in performance and perceived needs would be expected across a training period and into the competitive season.

From 1997, no more attempts have been made to scientifically investigate the construct and predictive validity of the Performance Profile within the sporting context. Since this date, the reported use of the Performance Profile within the research literature, cited references from educational manuscripts and from the recent survey have suggested that the Performance Profile is routinely used and is popular with sport-psychologists. It is more interesting to note that, considering the wide usage and applications of the Performance Profile, the scientific literature remains deficient.

In the most recent and only attempt to assess the reliability of the Performance Profile, the day-to-day reproducibility and single measurement of the Performance Profile was examined with recreational and intercollegiate athletes (Gleeson et al., 2005). An essential requirement of all outcome measures, including that of the Performance Profile, is to be valid and reproducible or reliable (de Vet, Terwee, Knol, and Bouter, 2006), and more purposely provide practitioners with a precise estimate of an individual's perceived current condition. Measurement precision in this context may be defined as the extent to which an athlete's Performance Profile and perceived current state on one testing occasion can be reproduced in subsequent tests or trials, conducted by the same participant in the same circumstances (Watson and Petrie, 2010).

Gleeson and colleagues (2005) within the initial assessment phase elicited an individual Performance Profile, each athlete selected ten to fifteen qualities from an inventory of qualities agreed upon by all the athletes, collectively, prior in a group discussion. These qualities were attributes that each athlete perceived to be important of an ideal sports-performer in each athlete's chosen sport or event. As with previous research, each athlete was asked to evaluate each quality on their Performance Profile by rating "where would you rate yourself at the present time on each of the qualities you have listed on a one to ten scale?"; [1] could not be any worse, to [10] could not be any better, respectively. In addition, athletes were also asked to consider, "how important are each of the qualities listed to an ideal sport-participant?" on a response scale, [1] not important at all to [10] of crucial importance, respectively - a higher importance rating of 10 was indicated at the outer perimeter of the Performance Profile chart, with rating becoming progressively lower towards the centre.

A secondary aim of this study was to investigate the accommodation responses of the Performance Profile. This was achieved by all athletes completing four practice sessions (within an accommodation phase) preceding three main experimental completions - main data collection which involved three consecutive completions of the same Performance Profile over a three-day period at closely matched times of day. The assessment of four practice attempts within an accommodation phase was to account for the possibility of a learning effect intruding on the precision of profiling (as previously recommended by Doyle and Parfitt, 1997). Each athlete's Performance Profile was reduced to the ten most important qualities for data analysis, determined by an athlete's importance ratings. Following analysis, there were no significant differences in perceived Performance Profile scores across the accommodation phase of four practice trials; which suggested that the completion of four practice profiles was adequate for athletes to adjust and habituate to the Performance Profile and, as such, suggests that the intra-subject changes in

Performance Profile scores across the subsequent three data collection points can be attributed to human variability, rather than to systematic learning effects.

As proposed by the authors, it is fundamentally important that practitioners utilising the Performance Profile have precise measurements of an athlete's perceived current state, therefore, when using the Performance Profile as a management outcome, a performance-intervention programme can be effectively implemented. However, the presented results suggested that the Performance Profile had a limited capacity to discriminate changes in an athlete's current condition, based on one single assessment of the Performance Profile. For example, the use of coefficient of variation (CV %) is a common utilised method to measure the acute variability associated with repeated assessments of outcome measures by the same individual (Gleeson and Mercer, 1996). Here, the CV% scores ranged between ±4.7% and ±6.8% for 68% confidence levels and between ±9.2% and ±13.3% for 95% confidence levels across the ten profile qualities. In turn, and as an example, if an athlete reports a CV% score of ±9.6% (95% confidence levels) it would suggest that practitioners can be 95% confident that the athlete's true Performance Profile score is actually somewhere between the values of 6.82 and 8.28 (7.55 ± 0.73), if the athlete had been scoring at approximately the group mean score on quality 1 (7.55). To further complicate the situation, it is expected that some perceived qualities (for example, strength capability) would not be expected to vary by more than 5% for elite athletes during a competitive season (Gleeson and Mercer, 1996), therefore, making it difficult to discriminate between error in measurement and actual real change.

The group mean CV% scores were used and were calculated to quantify the number of intra-subject completions of the Performance Profile that would be required to obtain an arbitrary criterion measurement error of ±5% (95% confidence levels). Here, a mean score of 10 completions of the Performance Profile would be needed to achieve a measurement precision of better than ±5% (95% confidence levels) for intra-subject comparisons across all of the 10 Performance Profile qualities. Furthermore, it could be argued that elite athletes within their peak of competition (and physical performance) would have Performance Profile ratings that would be approaching the optimal levels (denoted by perceived quality rating of 10), and would be subject to greater measurement error and would also require a larger number of replicates to achieve the criterion measurement error.

The presented study suggests that the Performance Profile had a limited capacity to discriminate the changes in the athlete's current condition based on a single-trial assessment. Therefore, the authors suggest that when utilising the Performance Profile in asymptomatic patients, where small changes in perceived current condition or performance are observed, it would be necessary to use a mean score associated with a minimum of 10 completions of the Performance Profile as the basis for estimating a performer's current condition. This would reduce measurement error and enhance precision of this technique. At times it would, therefore, be practically unsuitable to implement this with the athletes. As previously stated, the Performance Profile may, therefore, be more successfully utilised in other populations such as athletes during rehabilitation following an injury, as changes in performance and perceived capability would be expected to vary substantially in these participants during this period of recovery (Doyle and Parfitt, 1997; Doyle et al., 1998).

In summary, several attempts have been made to examine the validity of the Performance Profile in terms of the Performance Profiles' predictive and the construct validity (Palmer et al., 1996; Doyle and Parfitt, 1996; Doyle and Parfitt, 1997). As such, all of these studies have provided a useful preliminary insight into the validity of the Performance Profile (Weston et al., 2013). Doyle and Parfitt (1996) firstly hypothesised that the predictive validity would be shown if areas of the perceived needs identified by the Performance Profile were predictive of actual performance. The results of this study reported that a lower mean profile discrepancy score was associated with a higher performance score, and vice-versa.

Within another attempt to assess the Performance Profiles validity, Doyle and Parfitt (1997) hypothesised that the construct validity would be indicated if a greater area of perceived needs, identified by the Performance Profile, was reflected by a lower performance score. In contrast, construct validity would also be indicated by a smaller area of perceived need, identified by the Performance Profile, would be reflected by a higher performance score. The findings of this study gave some support for the construct validity of the Performance Profile as a significant reduction in perceived need was reflected by a significant increase in actual performance. Furthermore, an athlete's greatest perceived needs (the three most important qualities identified by each athlete) showed a greater and more rapid reduction across the athlete's competitive season, compared to the three least perceived needs (the three least important qualities, as identified by each athlete). This indicated a greater responsiveness and sensitivity in the three most important qualities, providing some support for construct validity. It was expected that the three most important qualities would have a stronger relationship with performance than the three least important qualities. However, the three most important and three least important qualities were only weakly correlated with performance.

Further, both of these studies suggested that the Performance Profile should be used cautiously with elite athletes. This is because it is unlikely that the Performance Profile has sufficient measurement sensitivity to accurately rate the relatively small changes in performance and perceived needs that have been observed across an athlete's training period and into a competitive season for track and field athletes. Thus, the authors concluded that deploying the Performance Profile during heavy periods of training, or within rehabilitation from injury where large changes in performance capabilities and perceived needs were likely, would be more suited to the application of the Performance Profile (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997;

Doyle et al., 1998; Gleeson et al., 2005). Within a recent review, Weston and colleagues (2013) reported that further empirical research is still required to assess the Performance Profile across a variety of sports, before substantive conclusions can be drawn as to the validity of the Performance Profile procedure.

CHAPTER THREE

STUDY 1

SYSTEMATIC REVIEW

The Relationship amongst Patient-Based and Clinician-Based Outcome Measures with Anterior Cruciate Ligament (ACL) Deficiency

3.1 - Introduction

Reliable, validated and responsive standardised outcome measures used in research (Swiontkowski et al, 1999) and clinical practice (Marshall et al., 2006) have repeatedly been described in the orthopaedic literature as important (Poolman et al., 2009), to monitoring progress and facilitating clinical decision-making during the rehabilitation process following surgery or injury (Bradbury et al., 2013; Reid et al., 2007; Irrgang and Lubowitz, 2008)

The use of P-BOMs[28] and C-BOMs[29] is important to comprehensively evaluate overall knee function from the perspective of the patient and physiotherapist. More specifically, C-BOMs are primarily used to evaluate impairment, while P-BOMs are used for the self-evaluation of activity limitations and participation restriction (Michener, 2011). Further, P-BOMs are necessary to understand what is important to a patient, to evaluate care, and in some instances, to assist in clinical decision-making processes (whilst documenting outcome), from the perspective of clinicians, to guide the treatment options available to their patients within clinical practice (Irrgang and Lubowitz, 2008; Bradbury et al., 2013).

The current literature seems to suggest that physiotherapists do not routinely incorporate P-BOMs in their current physiotherapy practice (Copeland et al., 2008; Jette et al., 2009; Swinkels et al., 2011). Although there are varying degrees of subjectivity involved in most physiotherapists' assessments, such as functional status and Quality of Life (QoL), and patient satisfaction, which can be more precisely reported by the patients themselves rather than by the clinician (Lloyd et al., 2014). C-BOMs (providing an objective measurement of impairment), however, are not subject to a large degree of individual interpretation, and are more likely to be reliably measured across patient recovery (or across a study design) by different healthcare professionals and over time (Velentgas, Dreyer, Nourjah, Smith, and Torchia, 2013), which perhaps explains this greater reliance on C-BOMs to justify clinical decisions regarding the management and treatment planning of patients, with less inclusion of P-BOMs.

A more plausible explanation though, is that physiotherapists are reporting that P-BOMs are at times impractical and unfeasible within the time constraints of clinical practice. Quite often, P-BOMs are reported as too complex and time-consuming to administer and evaluate within a defined consultation period (Phillips et al., 2000; Hammond, 2000). Furthermore, clinicians and clinical researchers alike have reported that they lack appropriate information and consequently the confidence to select appropriate P-BOMs within their own practice/research (Bent et al., 2009). For example, clinician may not understand how to understand and intercept normal distribution of scores of particular P-BOM in a clinical or general population, and do not therefore know what scoring cut-off points indicate that action is to be taken (Velentgas et al., 2013). To further

[28] Patient-Based Outcome Measure (P-BOMs).
[29] Clinician-Based Outcome Measure (C-BOMs).

complicate matters, only a few P-BOMs, specifically within ACL injury, have demonstrated satisfactory levels of reliability, validity, and responsiveness (Collins et al., 2011) [also see **TABLE 1** (p. 41)]. Thus, selecting a suitable P-BOM can be challenging for healthcare professionals and highlights the lack of this methodology's use within clinical practice (Dalton et al., 2012; Davidson and Keating, 2014).

As previously discussed in the introduction section of this thesis which evaluated relationships between P-BOMs and C-BOMs (see p. 45), with several evident recurring themes, the literature seems to suggest that there is a consistent lack of statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$)[30] (correlations amongst a range of P-BOMs and C-BOMs), explaining the challenges faced by clinicians and researchers. It should be pointed out, however, that from the relatively small number of studies evaluating P-BOMs and C-BOMs concomitantly, the evidence currently available shows that the heterogeneity of P-BOMs/C-BOMs makes them mostly non-comparable, with no same P-BOM being consistently evaluated with the same C-BOMs. The strength of the relationships between them therefore remains relatively speculative and warrants further investigation.

3.2 - Aims and Objectives of the Systematic Review

The purpose of this study **(Study 1)** is to evaluate the correlational relationship between P-BOMs and C-BOMs when administered concomitantly with ACLD and ACLR patients **(TABLE 3)**. The rationale for this Systematic Review is firstly to investigate which outcome measures (both P-BOMs and C-BOMs) are currently deployed within ACL literature to evaluate patient outcome. It will then be equally important to establish the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly within clinical research and up to 5 years post-ACL injury, and 5 years post-ACLR surgery (primary aim and objective). A recurring theme within the literature at present is the wide disparity in the strength of relationships (ranging from low to moderate) between P-BOMs and C-BOMs following different types of knee pathologies and surgeries (Chmielewski et al., 2011; Gandhi et al., 2008; Coman and Richardson, 2006; Maly et al., 2006; Kennedy et al., 2002).

Understanding the relationship between P-BOMs and C-BOMs is important for the thesis as whole[31], since at present it remains unknown which P-BOMs and C-BOMs should be deployed post-ACLR surgery and how they are related (Howe et al., 2012). A greater understanding of these relationships could also have important implications for clinical practice and governmental health care strategies. For example, within a rehabilitation setting, while a functional hop test would be

[30] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

[31] The secondary clinical research question of the thesis is to describe and understand the relationship amongst P-BOMs and C-BOMs (see p. 64).

impractical and unsafe in the acute stages of ACL rehabilitation when pain and swelling are present, and mechanical loading of the joint knee joint is contraindicated because a newly reconstructed ACL is maturing (Barber, Noyes, Mangine et al., 1992), if a P-BOM could be highly correlated with a C-BOM, then a P-BOM could instead be implemented as an alternative means to evaluate performance or function (Borsa et al., 1998; Lephart et al., 1992). Moreover, it would be prudent to understand the relationship between P-BOMs and C-BOMs at various points in different phases of rehabilitation, firstly to confirm whether P-BOM and C-BOM interactions do occur, and secondly, using the example above, alternative proxy use could be made of a P-BOM found to be significantly correlated with a functional hop to assess patient outcome at this time. Furthermore, with rising healthcare costs and continued debate over the appropriate number of outpatient physiotherapy sessions required in the recovery process (Coppola and Collins, 2009), the use of P-BOMs to assess patients in a domiciliary setting could have important implications in the self-management of patient care, with the potential for patient monitoring to be carried out at home with fewer physiotherapy appointments (Grant, Mohtadi, Maitlant, and Zernicke, 2005). Therefore, the subsidiary aim of the Systematic Review will be to establish whether the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly occur at different time points across an ACL rehabilitation programme (0-24 weeks).

Since the association or discordance between P-BOMs and C-BOMs evaluated concomitantly at 1 year and up 5 years post-ACL injury, or 1 year and up 5 years post-ACLR surgery is unknown, the third subsidiary aim is to investigate this association or discordance more longitudinally, up to five years, post-ACL injury and following ACLR surgery.

In addressing all of the above, it is equally important to critically evaluate whether both types of P-BOMs and C-BOMs are necessary within ACL recovery and throughout rehabilitation to assess patient outcome, and how such correlational information can be exploited in clinical practice, thus this will be the third subsidiary aim. Understanding the relationships among P-BOMs and C-BOMs might permit informed speculation over the number of outcome measure necessary within rehabilitation to correctly describe progression, and an understanding of the hierarchy of importance of outcome measures could help properly describe changes in functional capacity (Phillips et al., 2000). Specifically, in ACL deficiency, at present, the minimum number of either P-BOMs or C-BOMs needed to properly describe changes in patients' functional or physical performance during ACL rehabilitation, and the dilemma of whether P-BOMs or C-BOMs offer most validity remain unknown (Reiman and Manske, 2011).

In summary, this study **(Study 1)** attempted to compile information to address these research questions and aims by conducting a Systematic Review of the most up-to-date studies that have examined the relationships between P-BOMs and C-BOMs concomitantly when administered to patients with ACLD knees, or to patients who have undergone ACLR surgery, up to five years' post-injury or post-ACLR surgery. The importance of this Systematic Review is to critically evaluate whether both P-BOMs and C-BOMs are necessary within ACL recovery and rehabilitation and how these outcomes can be deployed in clinical practice to enhance patient care.

TABLE 3 - Study 1 aims and objectives.

STUDY 1	**To investigate the correlational relationship between P-BOMs and C-BOMs when administered concomitantly with ACLD and ACLR patients.**
Chapter 3 Systematic review	**(1)** To establish the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly within clinical research and evaluated up to 5 years post-ACL injury for ACLD patients, and 5 years post-ACLR surgery. **Subsidiary aims**: **(2)** To establish whether the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly occurs at different time-points in an ACL rehabilitation programme (0-24 weeks). **(3)** To identify the long-term association and discordance amongst P-BOMs and C-BOMs evaluated at 1 year and up to 5 years post-ACL injury for ACLD patients, and evaluated at 1 year and up to 5 years post-ACLR surgery for ACLR patients. **(4)** To critically evaluate whether both P-BOMs and C-BOMs are necessary within ACL recovery and rehabilitation.

3.3 - Methods

3.3.1 - Protocol

A review protocol was not used. This systematic review was performed broadly within the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2011). In addition, other sources of literature were sourced and assisted in the analysis and write-up of this review (Bettany-Saltikov, 2012; Wright, Brand, Dunn, and Spindler, 2007).

3.3.2 - Design and conduct

Following the guidelines provided by Bettanya-Saltikov (2012), a preliminary 'scoping search' was conducted, firstly, to assess via the Cochrane Centre and Library (www.cochrane.co.uk) and the Campbell Collaboration (www.campbellcollaboration.org) whether similar systematic reviews and/or meta-analyses had already been conducted or were in progress, and at the time of this review, none were published or in progress.

Secondly, prior to developing a systematic search strategy, a preliminary internet search using Google Scholar and other web-based searches was undertaken to source potentially relevant studies for inclusion in this review. A scan of any bibliographies was also undertaken to identify any further relevant studies for this review. These procedures allowed a greater understanding of search terms and MeSHs (Medical Subject Headings) frequently encountered and assisted in the construction of a suitable main search strategy.

3.3.4 - Inclusion and Exclusion criteria

For studies to be included in the review, they were required to meet certain inclusion criteria **(TABLE 4**; p. 119**)**, and all subjects had to be patients with symptomatic, ACL rupture who were being treated either conservatively or non-conservatively. Following ACLR surgery, all types of autograft sources and graft types were included, however, studies utilising synthetic ligaments and studies of posterior cruciate ligament reconstruction were excluded. This was to ensure that a standardised rehabilitation programme was followed, as using synthetic ligaments would result in patients performing different rehabilitation protocols (Legnani, Ventura, Terzaghi, Borgo, and Albisetti, 2010). All studies were required to be available in the English language as translation into English was not feasible within the timeframe of this review. Finally, only studies that were peer-reviewed were included in the review; all other types of unpublished material were excluded (with one granted exception).

For the purpose of this systematic review, it was necessary to identify relevant titles and abstracts, whereby, the aim of the study was to attempt to assess the correlations between P-BOMs and C-BOMs in ACL patients only **(TABLE 4**; p. 119**)**. Studies that did not evaluate P-BOMs and C-BOMs concomitantly were excluded from data analysis. Extraction of statistical results of correlations must have been reported for each study to be included in this review, as such all types of correlational statistics, for example the three most common: Pearson product-moment correlation coefficient (r), Spearman rank order correlation coefficient (r_s), and Kendall tau rank correlation coefficient (τ) were included[32]. It must have been possible to derive these correlational results from

[32] Consult Hauke and Kossowski (2011) for an explanation of correlation statistical tests, and further information on correlation coefficients used with Study 1.

the main text of each study, the presented correlational matrices or from other tabular or graphical representations.

TABLE 4 - Inclusion and exclusion criteria.

Inclusion criteria:	Exclusion criteria:
• Correlation investigations only, being either cross-sectional or longitudinal with prospective or retrospective designs. • Primary or secondary aim to assess the relationship between measures of self-report and performance-based assessments only. • Publications could be any type of research, which includes case studies, cross-sectional or cohort designs, case-controlled, or randomised controlled trials (RCTs). • Subjects with symptomatic, ACL ruptures either being treated conservatively or non-conservatively. • All types of autograft sources and types. • A self-report and a performance-based measure to be administered concomitantly at any assessment period prior to ACLR surgery or following ACL recovery. • The numbers of testing assessment were not stipulated. However, up to a maximum of 5 years' follow-up post-ACLR surgery. • Male or female subjects of any age. • Studies were required to be available in the English language.	• Correlational investigation where self-report and performance-based measures are not administered concomitantly. • Studies using other types of synthetic ligaments and studies of posterior cruciate ligament reconstruction. • Non-English language papers. • All cadaver and animal studies.

All studies were considered for this review and all had to be correlational investigations, being either a cross-sectional or longitudinal study with prospective or retrospective designs. The primary or secondary aims of each study had to include an examination of the relationships between P-BOMs and C-BOMs. In addition, in order to compare P-BOMs with C-BOMs, the latter had to be completed at the same time point as the P-BOMs, therefore, each study must have compared both outcome measures concomitantly. Studies that did not fulfil this criterion were excluded from data analysis.

The study population was confined to all ACL-confirmed ruptures. Partial ruptures or patients returning to surgery for revisions were excluded. ACLD individuals were defined as either ‘copers’, patients not requiring reconstruction surgery, or ‘non-copers’, patients whose experiences increased instability and recurrent subluxations, and as such, required ACLR[33] surgery (Eastlack, Axe, and Snyder-Mackler, 1999). All ACL individuals, including adolescents (13 years of age plus) and adults, both male and female, were included. Paediatric, prepubertal, and skeletally immature patients were excluded due to complexities in surgical management and significantly different rehabilitation protocols which may have to be adopted (McConkey, Bonasia, and Amendola, 2011).

Reviews, case studies and meta-analyses were not included in the primary search, but were read in order to provide ‘overall’ and ‘general perceptions’ of the understanding of the relationships between P-BOMs and C-BOMs before conducting this review.

The year of publication of each study varied, and for the purpose of this review no restrictions on year of publication were defined. The first three studies assessing the relationship between P-BOMs and C-BOMs concomitantly were conducted in 1988 (Harter et al., 1988; Kannus, 1988; Seto et al., 1988). Within the following decade, from 1990, 14 more studies were identified; these being the largest proportion of publications within this decade to examine the association between both methods of assessment (Chia and Chok, 1999; Risberg et al., 1999a; Risberg et al., 1999b; Risberg et al., 1999c; Sernert et al., 1999; Tyler et al., 1999; Borsa et al., 1998; Goh and Boyle, 1997; Neeb et al., 1997; Snyder-Mackler et al., 1997; Li et al., 1996; Harilainen et al., 1995; Wilk et al., 1994; Lephart et al., 1992). From 2000 to 2015, 13 studies were also identified (Holm et al., 2000; Hrubesch et al., 2000; Ross et al., 2002; Kocher et al., 2004; Bryant et al., 2008b; Bryant et al., 2008a; Gleeson et al., 2008; Park et al., 2010; Trulsson et al., 2010; Reinke et al., 2011; Baltaci et al., 2012; Kong et al., 2012; Yates et al., 2016).

The majority of studies (n = 13) were conducted in the USA or Australia (Borsa et al., 1998; Bryant et al., 2008a; Bryant et al., 2008b; Goh and Boyle, 1997; Harter et al., 1988; Kocher et al., 2004; Lephart et al., 1992; Reinke et al., 2011; Ross et al., 2002; Seto et al., 1988; Snyder-Mackler et al., 1997; Tyler et al., 1999; Wilk et al., 1994), with 12 studies conducted throughout Europe and Western Europe (Baltaci et al., 2012; Borsa et al., 1998; Gleeson et al., 2008; Harilainen et al., 1995; Hrubesch et al., 2000; Kannus, 1988; Neeb et al., 1997; Risberg et al., 1999a; Risberg et al., 1999b; Risberg et al., 1999c; Sernert et al., 1999; Trulsson et al., 2010), while a further four studies were conducted in Korea, Singapore, and Hong Kong (Li et al., 1996; Chia and Chok, 1999; Park

[33] Anterior Cruciate Ligament (ACL) Reconstruction (ACLR).

et al., 2010; Kong et al., 2012) (the reader is referred p. 113 and **APPENDIX 4** (p. 453) for the details of where each study was conducted).

3.3.5 - Type of interventions

All types of interventions were included, such as randomised trials to observational studies, as long as the main purpose of each study was to assess the relationships between P-BOMs with C-BOMs concomitantly. All studies were included if they performed ACLR arthroscopically, using either Bone-Patellar Tendon-Bone (BPTB), or Bone-Hamstring Tendon-Bone (BHTB) autografts. Autografts using hamstring tendon, combined with other musculature could be double- or multiple-stranded grafts and single- or double-incision techniques were also included. Any method of securing and fixation of grafts was included. Studies were excluded if allografts, synthetic materials and revision of ACLRs were used.

3.3.6 - Type of outcome measures

All outcome measures were included for analysis. C-BOMs could include all types of strength performance tests and protocols performed using dynamometry, all known measurements of knee laxity devices (either by manual or arthrometry systems), all routine clinical tests, balance tests, and other functional and performance-based activities, for example, all types of hop-jump performance tests for distance or time.

P-BOMs could include all types and measures of self-report, such as knee rating scales, instruments and questionnaires, for example, the IKDC, Cincinnati Knee Score, Tegner Knee Score, Lysholm Knee Score, and Visual Analogue Scales (VAS). Various P-BOMs (i.e., Lysholm, POPF) can be completed by both the patient and clinician, but only P-BOMs and C-BOMs concomitantly completed by an ACLD and ACLR patients could be included in the analysis. If a clinician had completed either outcome measure they would be excluded from analysis.

3.3.7 - Timing of outcome measure assessments

Studies were only to include P-BOMs and C-BOMs that were completed concomitantly from any time point following ACL injury, and from any period from ACL injury to surgery, and within any timeframe following surgery up to 5-years' post-ACLR surgery. It could be expected that ACLR individuals at 5 years' post-surgery would be at pre-injury level, therefore, a review of the relationships between P-BOMs and C-BOMs past this 5-year point was deemed unnecessary to this review.

3.3.8 - Search strategy for identification of studies

As reported by Relevo (2012), in order to access a large number of possible studies, more than one electronic database should be searched and search strategies should be individually tailored to each database (Honest, Bachmann, and Khan, 2003), since failure to do this could increase the risk of bias (Sampson et al., 2008; Stevinson and Lawlor, 2004). Three electronic databases were therefore systematically searched: EMBASE (from 1980 to 1st January, 2014), MEDLINE (from 1946 to 1st January, 2014) [using Ovid], and PubMed (from all years to 1st January, 2014).

Comprehensive search strategies were devised and applied in November 2012 with the assistance of a librarian specialising in physiotherapy using appropriate MeSH headings and keyword search terms necessary to identify suitable publications for inclusion within this review. The Systematic Review aimed for a high recall of literature which was low in specificity in the field of outcome measures and assessments. The search strategy used both controlled vocabulary (subject headings) and text words (Relevo, 2012). The search strategy was adapted to each of the databases searched (an example is presented in **TABLE 5**; p 124)[34]. A manual search of the journals and the authors encountered most frequently in the field was also conducted, and the reference lists of included research studies and past reviews were also searched to establish whether any studies not found in the electronic searches were potentially relevant for inclusion. This was in line with the recommendations of Khan and Kleijnen (2008).

3.3.9 - Searches

To conduct effective searches, comprehensive search strategies were developed for each database which included MeSH headings, search terms and key words while utilising appropriate Boolean phrases (the search strategies for the electronic databases are presented in **APPENDIX 3 (**p. 449). PICO (*Participants, Intervention*, *Comparison* and *Outcome*) is a method of constructing a search strategy that allows the reviewer to use a more evidence-based approach to the literature search when searching bibliographic databases like Medline (OVID). The used electronic databases were chosen to cover areas regarding P-BOMs and C-BOMs and were associated with ACLD/ACLR research. Key authors in the field were also contacted to enquire about any relevant research unpublished at the time of the review and to ensure no relevant studies were missed. References yielded by the electronic search were exported into Endnote X3 software (Thomson Reuters, NY, USA) for removal of duplicates, and to facilitate the systematic reviewing of titles and abstracts by both independent reviewers.

[34] For the remaining search strategies, see **APPENDIX 3 (**p. 449).

3.3.10 - Study Selection

The eligibility assessment was performed independently by two reviewers (CY and NG). The titles and abstracts of each study were examined in relation to the relevance to the topic, and any duplicates were removed at this stage. At this point, the studies were divided into the following categories: 'include', 'reject' or 'unsure'. If it was absolutely clear from the information provided in the title and/or abstract that the study was not relevant, then this publication was 'rejected', and would not be included in the review. Conversely, if the information provided in the title and abstract fulfilled the inclusion criteria with no indecision, the study would be considered for inclusion (and appropriately listed in the 'include' category). If abstracts were not available, or it was unknown from the title and/or abstract whether the study fulfilled the inclusion criteria, the complete article was reviewed for consideration at a later date.

The reviewers were not blinded to the author or journal name of each study. If any questions regarding inclusion or interpretation of the data arose, they were discussed by the two reviewers together (CY and NG). The full texts of the studies that were categorised in the 'unsure' category were then screened to identify whether or not they were eligible. However, for any studies whose eligibility for inclusion remained undecided a third reviewer was consulted and a decision was reached by group consensus. Inter-rater agreements for both reviewers were recorded and later compared. Where multiple studies used the same participant sample and the methodological design included the same P-BOMs and C-BOMs, the study that analysed the largest proportion of the sample was included, and the others studies were excluded to avoid the analysis of duplicate data or 'double counting' (Senn, 2009).

3.3.11 - Quality assessment

Two reviewers (CY and NG) independently assessed the methodological quality of all the studies included in the review. The methodological quality was conducted using a version of the 'Cochrane methods group on screening and diagnostic tests methodology' [abbreviated as CM for this review] (Devillé et al., 2002). However, in accordance with Gokeler et al., (2012), a modified version of CM was used to assess each study, as this modified version was more appropriate to the type and design of studies presented in this review. The following criteria were modified from the original CM version, and as suggested, questions one to four were replaced by the Oxford Centre for Evidence-based Medicine evidence levels (http://www.cebm.net/index.aspx?o=1025) to score the level of evidence from 1 to 5 (high to low score respectively) (Gokeler et al., 2012). The maximum score of the modified CM was 16 points.

TABLE 5 - Search terms (in search strategy format) used in the Medline electronic database search from 20th August 2013 to 10th April 2014 [**Key**: MeSH, Medical Subject Heading; .mp, text heading; * Boolean search phase].

Column terms combined **with**	Patient/condition **AND**	Intervention **AND**	Comparative Intervention **AND**	Outcomes **AND**
OR	1. Knee/	27. questionnaires.mp. or questionnaire/	95. Objective Outcome Measure*.mp.	**NONE**
OR	2. Knee*.mp.	28. psychological aspect/ or exp self-report/ or self-evaluation/ or Self-Report*.mp. or rating scale/	96. Clinician Reported Outcome Measure*.mp.	
OR	3. knee function/ or knee ligament injury/ or knee instability/ or knee injury/ or knee ligament/ or knee ligament surgery/ or knee cruciate ligament/	29. (Self-Report* or Questionnaire*) adj5 (Anterior Cruciate Ligament or ACL).mp.	97. Performance Based adj3 (Outcome* or Measure*).mp.	
OR	4. Knee Joint.mp.	30. Psychological Tests.mp. or psychologic test/	98. exercise test/ or excercise test.mp.	
OR	5. Knee Injuries.mp	31. Knee Rating Scale*.mp.	99. Functional Performance Test*.mp.	
OR	6. Athletic Injuries.mp	32. scoring system/ or outcomes research/ or Knee-Specific Instrument*.mp.	100. FPT.mp.	
OR	7. Sport Injury/	33. (Subjective or Patient Reported or Patient Assessed) adj5 (Outcome Measure* or Outcome* or Instrument or Measurement).mp.	101. Physical Fitness.mp. or fitness/	
OR	8. patient care.mp. or patient care/	34. PBOM* adj5 (Anterior Cruciate Ligament or ACL).mp.	102. Physical Performance Test*.mp.	
OR	9. preoperative care.mp. or preoperative care/ Preoperative adj3 (Anterior Cruciate Ligament Reconstruction or ACL).mp.	35. Quality of Life.mp. or "quality of life"/	103. Physical examination/	
OR	10. Postoperative adj3 (Anterior Cruciate Ligament Reconstruction or ACL).mp.	36. QoL.mp.	104. Physical Exertion/	
OR	11. Surger* adj5 (Anterior Cruciate Ligament or ACL).mp.	37. Sports Knee Scale.mp.	105. Physical examination.mp.	
OR	12. Ligaments.mp. or ligament/	38. AAOS.mp.	106. Diagnostic Test.mp. or diagnostic test/	
OR	13. Anterior Cruciate Ligament.mp. or anterior cruciate ligament/	39. Activity Rating Scale.mp.	107. Functional Outcome* adj5 (Anterior Cruciate Ligament or ACL).mp.	
OR	14. anterior cruciate ligament rupture/ or anterior cruciate ligament/ or ligament surgery/ or ACL.mp. or anterior cruciate ligament reconstruction/	40. Anterior Pain Questionnaire.mp.	108. Functional Test* adj5 (Anterior Cruciate Ligament or ACL).mp.	
OR	15. ACL Deficient Knee.mp.	41. Cincinnati Knee Rating System.mp.	109. Muscle Strength Dynamometer/	
OR	16. ACL Deficiency.mp.	42. Cincinnati adj5 (Anterior Cruciate Ligament Reconstruction or ACL)	110. Muscle Strength Dynamometer.mp.	
OR	17. anterior cruciate ligament rupture/ or Anterior Cruciate Ligament Replacement.mp.	43. Edinburgh Knee Function Scale*.mp.	111. Dynamometry.mp.	
OR	18. Orthopedic Procedures.mp. or orthopedic surgery/	44. EKFS.mp.	112. Muscle Strength/	
OR	19. Transplantation, Autologous.mp. or autotransplantation/	45. Functional Index Questionnaire.mp.	113. measurement/ or Range of Motion.mp. or joint mobility/ or "range of motion"/ or "movement (physiology)"/ or joint/ or muscle strength/	
OR	20. (Autograft* or Allograft*) adj5 (Anterior Cruciate Ligament or ACL).mp.	46. FIQ.mp.	114. Muscle Strength.mp.	
OR	21. tendon graft/ or Bone-Patellar Tendon-Bone Graft.mp. or bone patellar tendon bone graft/ or patella/ or tendon/ or bone graft/ or patella tendon/	47. International Knee Documentation Committee Subjective Knee Form.mp.	115. ROM.mp.	
OR	22. (Patellar Tendon or Hamstring Tendon) adj3 (Graft or Autograft*).mp.	48. IKDC.mp.	116. Muscle Contraction.mp. or muscle contraction/	
OR	23. (Double-Bundle or Single-Bundle) adj5 (Anterior Cruciate Ligament or ACL).mp.	49. Knee Injury and Osteoarthritis Outcome Score.mp.	117. Isometric Contraction.mp. or muscle isometric contraction/	
OR	24. rehabilitation/ or rehabilitation medicine/ or Rehabilitation.mp. or rehabilitation care/ or rehabilitation patient/ or athletic rehabilitation/ or rehabilitation research/	50. KOOS.mp.	118. Isotonic Contraction.mp. or muscle isotonic contraction/	
OR		51. Knee OA Severity Scale Knee.mp.	119. Muscle Contraction/ or exp Isometric Contraction/ or exp Isotonic Contraction/ or exp Muscle Relaxation.mp. or muscle relaxation/	
OR		52. Index of Severity for Knee Osteoarthritis.mp.	120. Electromyography/ or muscle isometric contraction/ or isometrics/ or Isokinetic Muscle Test*.mp. or quadriceps femoris muscle/ or isokinetic exercise/	
OR		53. ISK.mp		
OR		54. Knee Outcome Survey.mp.		
OR		55. KOS.mp.		
OR		56. Knee Outcome Survey–Activities of Daily Living.mp.		
OR		57. KOS-ADL.mp.		

3.3.12 - Data Collection Process

An extensive data extraction sheet was developed and used to extract all important and relevant information from the studies. The data extraction process was completed by two independent reviewers (CY and NG) to minimise reporting bias of the first reviewer. Authors of the included studies were contacted directly if questions arose about the reported data.

3.3.13 - Data items

Detailed information was extracted from each study, primarily, participant characteristics such as gender, age, graft type, mechanisms of injury, time from injury to ACLR surgery, and time from surgery to follow-up sessions, if available; the characteristics of the study, and the types of outcome measures assessed, such as P-BOMs and C-BOMs, were recorded. Correlation coefficient values were also extracted from each study[35].

Correlation coefficients are used to assess the direction and strength of the linear relationships between pairs of variables (Mukaka, 2012). For the purpose of this review, all types of correlation coefficients were included for analysis; however, depending on the nature of each study, the type of statistical test used was dependent on study design and whether both variables were normally distributed. For example, Pearson's correlation coefficient was used if the two variables were normally distributed. However, if this was not the case, Spearman's correlation coefficient would be a more robust means of assessment (Mukaka, 2012). Only correlation coefficients reported as statistically significant (at $p < 0.05$ level) and clinical relevant ($r \geq 0.70$)[36] within 'high' or 'very high' categories (see Hinkle et al., 2003), were evaluated for data analysis. Any remaining correlation coefficients were noted for observation and recorded as either 'not stated' or non-significant ('ns').

As reported by Di Fabio (1999), caution should be exercised when low or moderate correlation coefficients are assigned a significant p-value, as the p-value alone may result in misinterpretation of the relationships between variables. Furthermore, the assignment of a significant p-value to a low to moderate correlation coefficient can potentially be misleading since statistical significance and poor relationships can occur simultaneously (Clark, 2001). Therefore, the magnitude of correlation coefficient values should be looked at before considering the level of significance, as the correlation coefficient value presented indicates the degree to which two variables are correlated (Di Fabio, 1999; Greenfield, Kuhn, and Wojtys, 1998), as a significant correlation coefficient does not automatically dictate a robust relationship between two variables (Clark, 2001).

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[35] Consult **APPENDIX 7** (p. 515).

[36] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

For the purpose of this review, all correlations were examined and interpreted according to Hinkle et al., (2003); the reader is referred to **TABLE 6** (p. 126). However, only significant relationships ($p < 0.05$) were considered as relevant for the proposed research question. Studies assessing the relationship between the same pairs of variables, but using different correlation coefficients, may often report different results or different degrees of relationships (Hauke and Kossowski, 2011). According to Hinkle and colleagues (2003), a very `high' correlation exists between variables when the correlation coefficient value ('r', 'rs' and 'τ') is greater than 0.90. Correlation coefficient values between 0.70 and 0.89, 0.50 and 0.69 and 0.30 and 0.49 are considered high, moderate and low correlations, respectively (Hinkle et al., 2003). A correlation coefficient value below 0.30 would indicate no or a negligible correlation between two variables **(**see **TABLE 6)**.

TABLE 6 - Interpretation of size and strength of correlation as reported by Hinkle et al. (2003).

Size of correlation		**Interpretation**
0.00 to 0.29	(0.00 to - 0.29)	No or negligible correlation
0.30 to 0.49	(-0.30 to - 0.49)	Low positive (negative) correlation
0.50 to 0.69	(-0.50 to - 0.69)	Moderate positive (negative) correlation
0.70 to 0.89	(-0.70 to - 0.89)	High positive (negative) correlation
0.90 to 1.00	(-0.90 to - 1.00)	Very high positive (negative) correlation

3.3.14 - Summary measures

The primary outcome measure was the relationship between both P-BOMs and C-BOMs. Correlation coefficient values for each relationship were recorded.

3.3.15 - Participants and settings

A total of 15,092 studies was identified from the three electronic database searches, 2,721 of which were duplicates which when removed left 12,393 titles and abstracts to be examined for inclusion within the review. Following the examination of titles and abstracts, 12,340 publications did not meet the inclusion criteria. The overall level of agreement between both reviewers was fair ($\kappa = 0.26$). Subsequently, the full texts of 53 studies were assessed again by the two independent assessors after which 36 publications were excluded as they did not fulfil the inclusion criteria. Nineteen studies did not assess P-BOMs and C-BOMs concomitantly (Ahn et al., 2011; Andrade et al., 2002; Chmielewski et al., 2008; Chmielewski et al., 2011; Eitzen, Holm, and Risberg, 2009;

Fernandes et al., 2012; Grindem et al., 2011; Harreld, Hyland, Cottrell, and Caborn, 2006; Herrington, Turner, and Horsley, 2004; Jarvela, Kannus, Latvala, and Jarvinen, 2002; Karasel et al., 2010; Kocher et al., 2002; Lephart et al., 1992; Lopomo et al., 2008; McGuine, Winterstein, Carr, Hetzel, and Scott, 2012; Reid et al., 2007; Schmidt-Rohlfing et al., 2011; Shaw, 2001; Shiraishi et al., 1996), 9 studies did not report correlational results pertinent for the purpose of this review (Pantano et al., 2001; Chmielewski et al., 2002; Eastlack et al., 1999; Lavoie et al., 2001; Moksnes and Risberg, 2009; Moksnes et al., 2008; Ross, 2010; Pollet et al., 2005; Higuchi et al., 2003), one study did not examine ACL patients, though it did examine the relationship between P-BOMs and C-BOMs with osteoarthritis patients (Jacobs and Christensen, 2009), one study examined patients with synthetic allografts (Hyder, Bollen, Sefton, and Swann, 1997), two publications were review articles (Fitzgerald et al., 2001; Pua et al., 2008), one study was a conference abstract, which at the time of this review was not intended to be published (author was contacted to confirm this) (Banff et al., 1999), and the remaining two studies were not published in the English language (Dejour et al., 2008; Dubljanin-Raspopovic, Matanovic, and Kadija, 2005).

The summary of the study selection process can be seen in **(FIGURE 8**; p. 128**)**

TABLE 7 (p. 130) sets out the demographic characteristics of the participants for the included studies for all ACLR and ACLD patients (the healthy control group's data is not reported). The studies had a total of 2,150 participants, with the number of participants in each study ranging from 9 to 527. The participant sample could be divided into three distinct groups or comparison within groups; these consisted of seven studies examining ACLD participants (Borsa et al., 1998; Harilainen et al., 1995; Kannus, 1988; Lephart et al., 1992; Li et al., 1996; Park et al., 2010; Snyder-Mackler et al., 1997), 19 studies examining ACLR participants (Bryant et al., 2008b; Chia and Chok, 1999; Gleeson et al., 2008; Goh and Boyle, 1997; Holm et al., 2000; Harter et al., 1988; Hrubesch et al., 2000; Kocher et al., 2004; Neeb et al., 1997; Reinke et al., 2011; Risberg et al., 1999b; Risberg et al., 1999c; Ross et al., 2002; Seto et al., 1988; Sernert et al., 1999; Trulsson et al., 2010; Tyler et al., 1999; Wilk et al., 1994; Yates et al., 2016), one study examining both ACLD and ACLR participants together (Bryant et al., 2008b), and finally three studies compared ACLR participants with healthy participants acting as a control group (Baltaci et al., 2012; Kong et al., 2012; Risberg et al., 1999a).

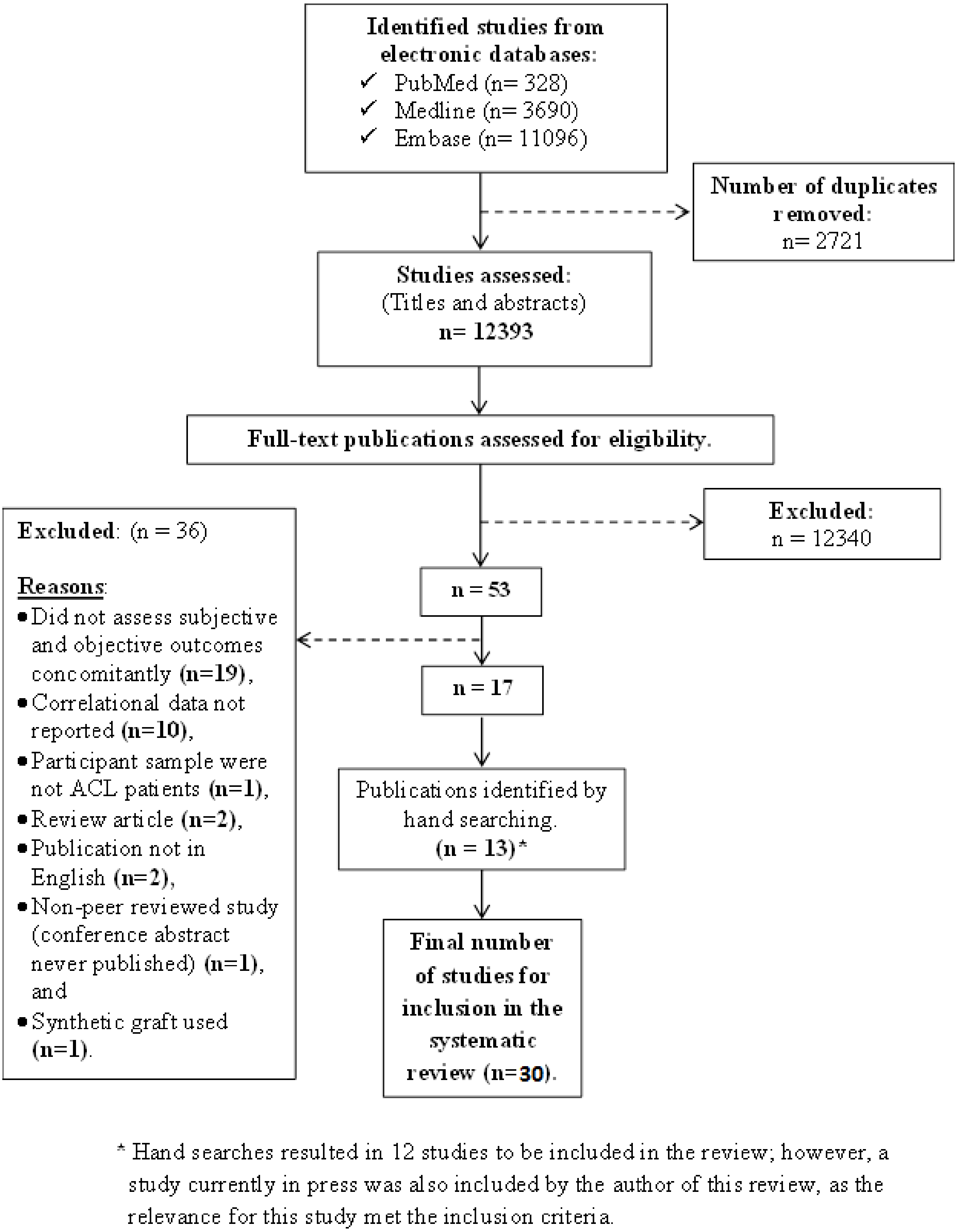


FIGURE 8 - Summary of the study selection process.

With regards to the gender of participants, a higher number of male participants (n = 1,307) were included in the studies than female participants (n = 727). Two studies did not report participant gender (Kannus, 1988; Snyder-Mackler et al., 1997), therefore, the gender of 106 participants was unknown. The mean age of the participants for all the studies was 28.93 years, with an age range from 14 to 62 years, and most studies included the age of the participants with standard deviations scores following. However, several studies lacking this detail. In addition, demographic data such as height and body mass were not apparent from the majority of the studies; the studies (n = 14) that did present such values were converted into centimetres for body height, and kilograms for body mass.

While some studies did not report the study settings, participant evaluations either took place in a laboratory-based setting within primary care practices or in a hospital setting, typically within rehabilitation centres. Finally, within the 23 studies which examined ACLR participants, the graft types used for ACL replacement were all autologous grafts, being either Bone-Patellar Tendon-bone (BPTB) or Semitendinosus-Gracilis (ST-GRA) grafts, with only one study using a Semitendinosus (ST) graft (Kong et al., 2012). Fourteen studies used BPTB grafts only, with four studies using both types of graft (Chia and Chok, 1999; Harter et al., 1988; Kocher et al., 2004; Bryant et al., 2008a). Only one study used a ST-GRA graft alone (Ross et al., 2002). However, four studies did not report the graft type used for reconstruction (Neeb et al., 1997; Seto et al., 1988; Reinke et al., 2011; Kong et al., 2012), therefore, graft types were unknown for 126 participants.

TABLE 7 - Participants' demographic data as evaluated from all studies from systematic searches (Table is the author's own research).

	ACL-R participants									ACL-D participants						
	Number, (♂:♀)		Age, years (SD)	Height, cm (SD)	Mass, Kg (SD)	Graft type	Time of injury to surgery (SD)	Time from surgery to evaluation (months)	Additional injuries	Number, (♂:♀)		Age, years (SD)	Height, cm (SD)	Mass, Kg (SD)	Time of injury to evaluation (SD)	Additional injuries
Banff et al (1999)	50*		23.7 (NR)	NR	NR	NR	NR	5-7	NR							
Bryant et al (2007)	9	4	33.2 (12.9)	164.4 (22.3)	87.4 (30.9)	BPTB	NR	6-9	No							
Chia and Chok (1999)	21		26.4 (NR)	NR	NR	7x BPTB 11x ST-GRA	NR	3, 6	2x Med. Meniscus. 1x MCL							
Gleeson et al (2008)	7	2	29.9 (8.7)	169.0 (35.0)	73.85 (6.8)	BPTB	20.4 (13.2)	2 wks prior, 6, 8,10 wks[a]	NR							
Goh and Boyle (1997)	15	5	28.0 (NR)	NR	NR	BPTB	NR	24-48	NR							
Harter et al (1988)	32	19	23.7 (NR)	NR	NR	31x BPTB 20x ST-GRA	22.1 (NR)	48 (20.9)	NR							
Holm et al (2000)	85	66	28.0 (8.6) (8.6)	NR	NR	BPTB	27.0 (49.0)	6, 12, 24	NR							
Hrubesch et al (2000)	26	18	33 (NR)	NR	NR	BPTB	7.5 (NR)	19 (NR)	28x Meniscus. 4x MCL. 1x LCL.							
Kocher et al (2004)	115	87	28.6 (NR)	NR	NR	177x BPTB 25x ST-GRA	NR	35.9 (NR)	No							
Neeb et al (1997)	17	13	28.5 (8.3)	NR	NR	NR	NR	NR[2]	15x Med.Meniscus.							
Risberg et al (1999b)	64	56	27.8 (NR	NR	NR	BPTB	27 (NR)	3, 6, 12, 24	53x Meniscus. 11x MCL.							
Risberg et al (1999c)	32	28	29.6(10.1)	NR	NR	BPTB	26.0 (54.1)	3, 6, 12, 24	23x Meniscus. 5x MCL.							
Ross et al (2002)	36	14	20.6 (1.3)	178 (9.2)	79.9 (13.8)	ST-GRA	1.2 (0.8)	28.9 (15.5)	NR							
Sernet et al (1999)	349	178	26 (NR)	NR	NR	BPTB	12 (NR)	38 (NR)	108x Med. Meniscus. 46x Lat. Meniscus. 62x Med. Lat. Menisc. 53x Chondral							
Seto et al (1988)	19	6	31.4 (7.31)	NR	NR	NR	23.37 (26.6)	58.03 (0.74)	No							
Trulsson et al (2010)	38	15	30.0 (5.2)	NR	NR	BPTB	24-60	36 (8.2)	NR							
Tyler et al (1999)	46	44	31.0 (8.0)	NR	NR	BPTB	NR	13.0 (3.0)	NR							
Wilk et al (1994)	34	16	24.5 (NR)	170 (NR)	75 (NR)	BPTB	NR	6.50 (NR)	NR							
Yates et al (2013)	5	4	31.3 (9.7)	168.0 (5.0)	73.9 (7.8)	BPTB	23.4 (18.9)	2 wks prior 6, 8 and 10 wks#	NR							
Reinke et al (2011)	28	41	20.5 (NR)	177 (NR)	75.3 (NR)	NR	35.4 (NR)	26.4 - 38.4	NR							
Baltaci et al (2012)	15		29.6 (5.9)	176.4 (8.3)	77.7 (10.3)	BPTB	NR	20 (3.1)	NR							
Kong et al (2012)	30		23.43 (3.17)	177 (7.07)	77.07 (8.41)	ST	NR	≥ 6	4x Med. Meniscus. 1x Med. Meniscect. 4x Lat. Meniscect.							
Risberg et al (1999a)	8	12	35 (NR)	NR	NR	BPTB	4.6 (NR)	24 (NR)	9x Meniscus. 5x Par. Meniscect. 2x MCL Grade-I.							
Bryant et al (2008)	27		26.9 (5.8)	178.4 (4.9)	83.25	13x ST-GRA	16.6 (4.7)	14.2±4.5	No	10		30.7 (8.6)	176.2 (5.0)	72.4 (4.8)	75.6 (72.5)	No
Borsa et al (1998)										15	14	28.7 (1.7)	NR	NR	41.7 (11.7)	5x Par.Med Meniscect. 2x MCL G-III.
Harilainen et al (1995)										98	69	28.7 (NR)	NR	NR	32.4	NR
Kannus (1988)										36*		34 (NR)	NR	NR	8.0 (2.1)	No
Snyder-Mackler et al (1997)										20*		27.7 (NR)	NR	NR	2, 6	No
Lephart et al, (1992)										32	9	22.7 (NR)	NR	NR	26.5 (NR)	NR
Li et al (1996)										28	18	24.15 (6.32)	NR	59.65 (7.35)	NR[1]	14x Meniscus.
Park et al (2010)										40		27.0 (7.2)	71.1 (6.28)	73.15 (11.7)	3.75 (2.5)	No

3.4 - Results

This section of the Systematic Review will report upon the outcomes of the systematic review, firstly by evaluating the P-BOMs and C-BOMs found, separately. Secondly, a general results section will be discussed evaluating generalised outcomes of the systematic review. Following this, the proposed research aims will be discussed by examining the degree of association or discordance between P-BOMs and C-BOMs. Due to the heterogeneous nature of the studies included in this review, in terms of the wide variety of outcome measures (for both P-BOMs and C-BOMs) and the nature of study designs, it was deemed not possible to perform a meta-analysis on the full set of studies found, and meta-analyses on a small number of sub-sets was deemed unworthy. Thus, it was thought to be more appropriate to perform a narrative synthesis on all studies **(APPENDIX 6**; p. 486**)**. No meta-analysis was performed. A full breakdown of the 30 studies can be seen in **TABLE 8** (and continued in **APPENDIX 4** (p. 453).

3.4.1 - Outcomes Measures

3.4.1.1 - Patient-Based Outcome Measures

For inclusion in the review, all studies had to administer both P-BOMs and C-BOMs concomitantly, as such, a multitude of P-BOMs were reported within the 30 studies presented studies **(TABLE 8**; next page**)**. In total, 33 unique P-BOMs were used to assess ACL-related outcomes from the patient's perspective. As seen in **TABLE 9**, the frequency of P-BOMs found are reported. Here, 27 named P-BOMs were found within the reviewing process with correlational data reported, however, 6 P-BOMs were reported with no correlational values, therefore, these were excluded (i.e., Hospital for Special Knee Score, HSS).

There was a wide variety of P-BOMs utilised and reported within the thirty studies **(APPENDIX 5**; p. 484**)**. For the purpose of this review, each P-BOM was identified and was divided into a classification of type of outcome measure as suggested by Fitzpatrick et al., (1998). Fitzpatrick and colleagues reported that a clear distinction between P-BOMs is a useful means of considering the range and varying types of outcomes measures available, however, as stated, this classification should not be too rigorous in selection as many P-BOMs will have elements from more than one category. P-BOMs can generally be categorised as being Generic, Disease-Specific, Population-Specific, and/or Site- or Region-Specific (Garratt et al., 2004). Additionally, P-BOMs can be divided into Dimension-Specific, Summary items, Individualised, and Utility-Based P-BOMs (Fitzpatrick et al., 1998).

The majority of P-BOMs were from the 'Site-/Region- (joint) specific' outcomes associated with ACL-related outcomes. In addition to the above P-BOMs which use standardised sub-scales and defined questions, 'analogue scales' were used in several of the studies included in this review. Analogue scales may either be Numerical Rating Scales (NRS), or Visual Analogue Scales (VAS).

TABLE 8 - A sample of one of the studies included from the review (the remaining 29 studies are continued in **APPENDIX 4** [p. 453]).

AUTHOR(S) / YEAR / STUDY TYPE	**AIMS & PURPOSE**	**POPULATION DEMOGRAPHICS**	**OUTCOME MEASURES** **P-BOMs vs. C-BOMs**		**MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS**	**RESULTS** **Correlations between subjective self-report and objective, functional, and performance based outcome measures**		**AUTHORS CONCLUSION**	**COMMENTS**
Baltaci, Yilmaz, & Atay (2012) **Study**: Correlational study **Location**: Turkey	To compare the relationship between functional performance and muscle strength with ACL-reconstructed knees and age-matched healthy individuals acting as the control group.	**ACLR participants:** **n**=15: (15♂). **Age**: 29.6±5.9 years. **Height**: 176.4±8.3 cm. **Mass**: 77.7±10.3 kg. **Graft**: BPTB autograft (n = 15). **CONTROL*:** **n=15** (15♂). **Age**: 27.0±6.2 years. **Height**: 176.7±6.9 cm. **Mass**: 76.7±5.7 kg. *15 males of similar age with no systematic disease (No significant differences between groups).	**HSS.** **Lysholm.** **Tegner.**	**Dynamometry** (Cybex6000, tested peak torque of flex. & ext. at 60°x5 &180°x10). **ROM.** **Ladder-hop-test**. **Vertical-jump-test.** **Slope-test.** **Stairs-test**. **Carioca.** **Side-run test.** **Figure-8 test.** **Shuttle-run-test 1.** **Shuttle-run-test 2.** **Triple-crossover-hop-test.** **Single-leg-triple-hop test.** **Single-leg-hop test.**	**Follow-up after ACLR surgery:** 20±3.1 months. Tegner activity scale measured pre- and post-operatively in ACL group. Correlation coefficient assessed by 'r_s' to evaluate relationships (Significance level set at $p<0.05$).	Lysholm/Single-leg-hop test. Lysholm/Single-leg-triple-hop-test. Lysholm/Triple-crossover-hop-test. Lysholm/Ladder-hop-test. Lysholm/Vertical-jump-test Lysholm/Shuttle-run-test 2. Lysholm/Stairs-test Tegner/Single-leg-hop test. Tegner/Single-leg-triple-hop test. Tegner/Triple-crossover-hop-test. Tegner/Ladder-hop-test. Tegner/Vertical-jump-test Tegner/Shuttle-run-test 2. Tegner/Stairs-test Tegner/Flex. Iso 180°/s **$*p<0.05$**	**0.56*** **0.55*** **0.66*** **0.62*** 0.08 0.02 0.25 0.13 0.08 0.28 0.37 0.15 **0.57*** 0.70 **0.52*** **=r_s**	Functional outcomes similar to those of healthy legs can be achieved following ACL reconstruction with BPTB grafting and rehabilitation. The similar functional test results of the operated and healthy subjects prove the effectiveness of the rehabilitation program.	**Considering the high number of objective tests presented, little correlational data was reported. The majority of relationship data compared objective and functional assessments only.** **Detailed descriptions and administration of all outcome measures were thoroughly reported.**

TABLE 9 - Frequency of reported cases of use of P-BOMs found within Systematic Review of both significant and non-significant correlations (P-BOMs and C-BOMs)[37].

Patient-Based Outcome Measures (P-BOMs)	Frequency of P-BOMs reported
1. Cincinnati Knee Rating Scale (Cincinnati)	85
2. Lysholm Knee Rating Scale (Lysholm) [**total/component**]	48/7*
3. International Knee Documentation Committee (IKDC) Evaluating Form [**total/component**]	2 /22*
4. Noyes Knee Rating Scale (Noyes) [modified]	26
5. Tegner Activity Scale (Tegner)	25
6. Functional Activity Scale (FAS)	24
7. Knee injury and Osteoarthritis Outcome Score (KOOS)	18*
8. Performance Profile	18
9. Visual Analogue Scale (VAS)	17
10. Iowa Athletic Knee Rating Scale (IAKS)	12
11. Knee Function Rating Form (KFR)	8
12. 10-Point Knee Scale (10-PT)	7
13. Activity Rating Scale (ARS)	7
14. Post-Operative Physical Finding (POPF) form	7
15. Bipolar Profile of Mood States (Bi-POMs)	6
16. Factor Occupational Rating System Scale (FORSS)	5
17. Sports Activity Rating Scale (SARS)	5
18. Marx activity level (MARX)	4
19. [Activities of Daily Living Scale (ADLS); Knee Outcome Survey (KOS); and Sports Activity Survey (SAS)]	3
20. Emotional Responses of Athletes to Injury Questionnaire (ERAIQ)	3
21. Global knee scale (GKS)	2
22. ADL level	1
23. Feagin and Blake Knee Score (Feagin and Blake)	1
24. Marshall Knee Scores (Marshall)	1
25. Orthopaedic Working Group Knee Score (OAK)	1
26. Work level	1
27. Zarins and Rowe Rating Scale (Zarins and Rowe)	1
	TOTAL: 388

[37] NOTE: Total and component scores* for IKDC, KOOS and Lysholm.

NRS allow the patient to quantify the degree of pain or dysfunction they perceive at a particular time, as indicated with a single number, typically on a scale of between one and ten (Clark, 2001). Description anchors are provided for the extreme ends of the scale to provide reference points for the patient to consider (Kersten, Kucukdeveci, and Tennant, 2012). VAS utilise the same principle, however, this method involves the use of a vertical mark on a horizontal line, with verbal or written descriptors at the extremes of the horizontal lines, rather than numbers, to provide reference points for the patient to consider (Shaw et al., 2005; Flaherty, 1996).

Within the included studies, analogue rating scales, NRS (n = 2)[38] (Harter et al., 1988; Goh and Boyle., 1997) and VAS (n = 2) Snyder-Mackler et al., 1997; Wilk et al., 1994) were used to assess patient outcomes. Tyler et al., (1999) reported using an analogue scale to measure subjective ratings of knee instability, though the type and methods used (NRS or VAS) were not described. Two studies used P-BOMs that were categorised as an 'individualised outcome' (Gleeson et al., 2008; Yates et al., 2016). Individualised outcome measures are described as P-BOMs, whereby the individual completing this outcome is allowed to select his or her own issues, domains or concerns that are of personal interest, and are not confined to predetermined questions (Fitzpatrick et al., 1998). In this context, the individual is encouraged to identify aspects of their life that have been affected by injury or poor health, without imposing any standardised list of potential answers (Ruta and Garratt, 1994).

One of the studies (Gleeson et al., 2008) used the 'Emotional Responses of Athletes to Injury Questionnaire' (ERAIQ), which was developed from interviews examining how an injured athlete was presently feeling about his or her injured state. The ERAIQ questionnaire was administered to injured athletes by asking three questions to assess their emotional response to injury. The injured athlete is asked to rate how they are feeling because of their injury, firstly by suggesting four words in order to determine the type of emotional response. Secondly, a list of words is then provided from which the injured athlete chooses four which best describe how they are feeling due to their injury, in order to determine the type of response. Thirdly, the injured athlete rates the list of emotions using a 5-point Likert scale from (1) 'absolutely not' to (5) 'extremely so', in order to measure the magnitude of emotional response.

Gleeson and colleagues (2008) also implemented an 'Individualised' outcome measure known as the Performance Profile. The Performance Profile is constructed by the injured athletes and physiotherapists in a discussion about the athletes' emotional perceived needs following their injury. The athlete here selects his or her own words that best describe his or her current perceived state. To elicit an emotional Performance Profile, the injured athlete is asked to consider the following question, "emotionally how are you feeling since your injury?" The exact words (or items listed) are mapped onto the Performance Profile chart. Following this, the athlete is asked to

[38] n = Number of P-BOMs found.

consider another question, “how are you feeling at the present time on each of the emotions you have listed?” Subsequently, the injured athlete rates each construct response using a 1 to 10 scale, such as ‘not at all like this’ to ‘very much like this’.

Similarly, Yates et al. (2016)[39] further investigated this profiling technique with ACL-injured athletes; however, physical responses were elicited as opposed to emotional responses which were utilised to see if physical self-perceived needs would, in turn, elicit similar results in the context of musculoskeletal performance in a symptomatic population of ACLD and ACLR patients. Although Yates et al. (2016) was under review at the time of this thesis, and therefore did not meet the inclusion criteria of being a published or peer-reviewed study, given the little empirical work currently investigating the Performance Profile and since it met the remaining inclusion criteria, this study was included.

To elicit a physical Performance Profile, the injured athlete is asked to consider the following question, “what, in your opinion, are the elements of your knee in need of rehabilitation or improvement to obtain full recovery? The exact words (or items) reported by the athlete are mapped onto the Performance Profile chart. Following this, the athlete is asked to consider another question, “how does your injured limb feel at the present time compared to your non-injured limb on each of the items you have listed?” The injured athlete then rates each construct using a 1 to 10 scale, from “extremely different to my non-injured limb” (1) to “the same as my non-injured limb” (10).

[39] Unpublished research and under review.

TABLE 10 - Frequency of reported cases of use of P-BOMs found within the Systematic Review for significant correlations ($p < 0.05$) only ($n = 117$) (P-BOMs and C-BOMs). **NOTE:** Total and component scores* for IKDC, KOOS and Lysholm.

Patient-Based Outcome Measures (P-BOMs)	Frequency of P-BOMs reported
1. Cincinnati Knee Rating Scale (Cincinnati)	24
2. Performance Profile	18
3. Lysholm Knee Rating Scale (Lysholm) [**total/component**]	15/1*
4. Noyes Knee Rating Scale (Noyes) [modified]	11
5. International Knee Documentation Committee (IKDC) Evaluating Form [**total/component**]	4/7*
6. Tegner Activity Scale (Tegner)	7
7. Bipolar Profile of Mood States (Bi-POMs)	6
8. Functional Activity Scale (FAS)	4
9. Knee injury and Osteoarthritis Outcome Score (KOOS)	4*
10. Visual analogue scale (VAS [Pain])	4
11. Post-Operative Physical Finding (POPF) form	4
12. Activity Rating Scale (ARS)	3
13. Emotional Responses of Athletes to Injury Questionnaire (ERAIQ)	3
14. Sports Activity Rating Scale (SARS)	1
	TOTAL: 117

3.4.1.2 - Clinician-Based Outcome Measures

Alongside the use of P-BOMs found within the thirty studies, a total of 122 clinician-derived outcome measures was initially found. However, the use of different names for the same tests, clinical or other clinician-derived naming/classifications, made categorising clinician-based tests/outcome measures a complex task. For example, several designations had been given to various hop-based performance tests, such as long hop and triple hop. Therefore, on further inspection, it could be found that the long hop referred to a Single-Leg Hop for distance and a single-leg-triple-hop for distance, as hop-based tests/outcomes executed the same movements and led to the same outcomes. Therefore, all clinician-based tests/outcome measures were categorised together **(FIGURE 9**; p. 138**)**.

After categorising C-BOM, 41 unique outcome measures were found by comparing these C-BOMs to P-BOMs (n = 388). Several studies reported using C-BOMs (i.e., figure of 8, side-hop-test, and thigh circumference measurements), however, these C-BOMs were not directly correlated to any P-BOMs and, were thus excluded (see inclusion criteria, **TABLE 4**; p. 119). C-BOMs were categorised into the following categories: **[1 :] (a)** Hop-based test evaluated by distance, and **(b)** hop-based test evaluated by time]; **[2 :]** Agility tests evaluated by time; **[3 :]** Knee arthrometry measurements in the evaluation of knee laxity; **[4 :]** Clinical; **[5 :]** Assessment of proprioceptive performance and sensation; **[6 :]** Assessment of balance; and **[7 :]** Assessment of muscle strength and neuromuscular performance evaluated by dynamometry **(**see **FIGURE 9**; p. 138**)**.

On examination of classification categories for C-BOMs, it was apparent that a large range of C-BOMs were used to assess ACLD and ACLR knees from the perspective of the clinician. The most popular were assessed by dynamometry examining various muscle strength and knee performance variables (i.e., Peak Torque [PT], Total Work [TW], and various angular knee velocities ranging from 60 - 450°/s, etc.) for the knee flexors and extensors. Neuromuscular outcome measures (C-BOMs), such as Peak Force (PF), Electromechanical Delay (EMD) and Rate of Force Development (RFD) were also found to assess patient outcomes.

Measurement of knee laxities evaluated by arthrometry systems (KT-1000, KT-2000, and CA-4000) were also the most chosen methods of assessments, with the KT-1000 arthrometer being the most popular means of knee assessment, accounting for 62 of the 72 laxity outcome measures found. The jump-based tests/outcomes evaluated by a Single-Leg Hop for distance and time (21 and 9, respectively) were the most widely used functional hop-based outcome. Within this sub-group, hop-based tests/outcomes, the single-leg-triple-hop (n = 9) and single-leg-triple-crossover-hop (n = 9) for distance were other widely-reported outcomes. Clinical tests/outcomes performed by clinicians directly, were used to assess the knee and ACL integrity. Manual methods of assessment included the lateral-pivot-shift (n = 2), pivot-shift (n = 4), anterior-draw (n = 4), and principally the most common test/outcome was the manual-Lachmans (n =18) test/outcome. The measure of knee angle (i.e., measurement of knee flexion and knee extension), evaluated by goniometry was a particular clinical test/outcome reported.

Similarly, as with hop-based tests/outcomes which assessed a timed single-leg 'functional' hop over predetermined distances (i.e., 6m, 10m and 12m), agility tests/outcomes were also regularly reported within the thirty studies found. More specifically, these clinician-observed tests/outcomes were the stairs-hopple (n = 2), ladder-hop (n = 2), Carioca (12m) (n = 3), co-contraction (n = 3), stairs-step (n = 2), and shuttle runs at 12m and 24.4m (n =2 and n = 3 respectively). Finally, balance and proprioception, and sensation tests/outcome were also reported, and although they were sparse, they were compared to the aforementioned results.

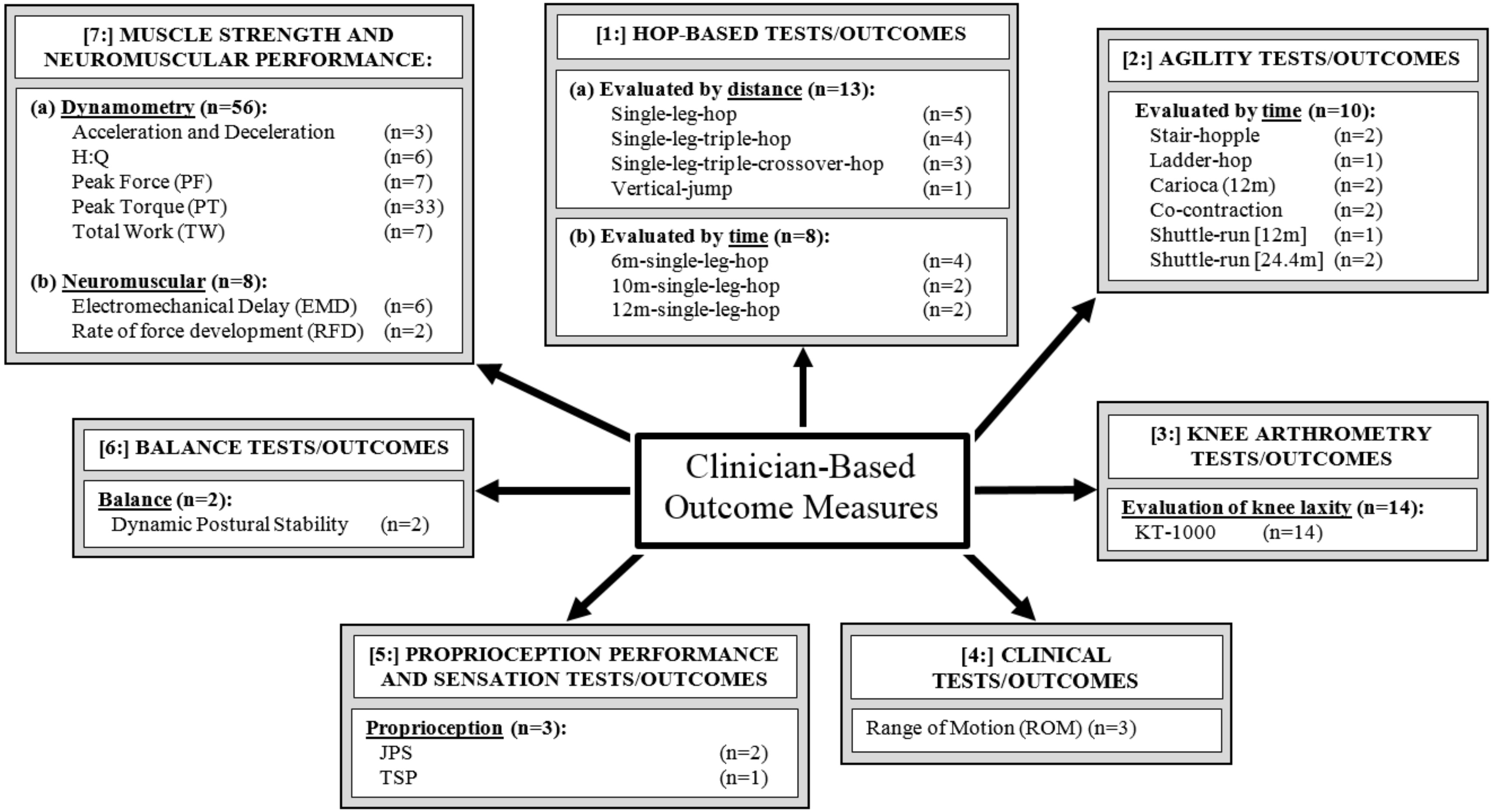


FIGURE 9 - Classification of clinician-based tests/outcomes assessed from the clinician's perspective as found from the results of the systematic reviewing process. **NOTE:** Total number of significant correlations found (n = 117) and frequency of each test/outcome within each sub-group category (i.e., hop-based tests/outcomes) (Source: Author's own diagram).

3.5 - General Results of the Systematic Review

Thirty correlational investigations were found that matched the inclusion and exclusion criterion. The participant samples from all 30 studies could be divided into three distinct groups or comparisons within groups; these consisted of 7 studies examining ACLD individuals, 19 studies examining ACLR individuals, 1 study examining both ACLD and ACLR individuals together, and finally 3 studies comparing ACLR individuals to healthy participants acting as a control. On further examination of the thirty studies, 18 studies reported significant correlations (at $p< 0.05$ level) between P-BOMs and C-BOMs when evaluated concomitantly with a range of correlation coefficients. Whilst the remaining 12 studies reported no significant ($p> 0.05$) correlations

In total, 388 correlations were found that assessed P-BOMs and C-BOMs in the 30 studies. Three types of correlation coefficients were found within the screening of the 30 studies: Pearson's product-moment correlation coefficient [r: (n) = 225][40], Spearman's rank order correlation coefficient [r_s: (n) = 124], and Kendall's tau rank correlation coefficient [τ: (n) = 39].

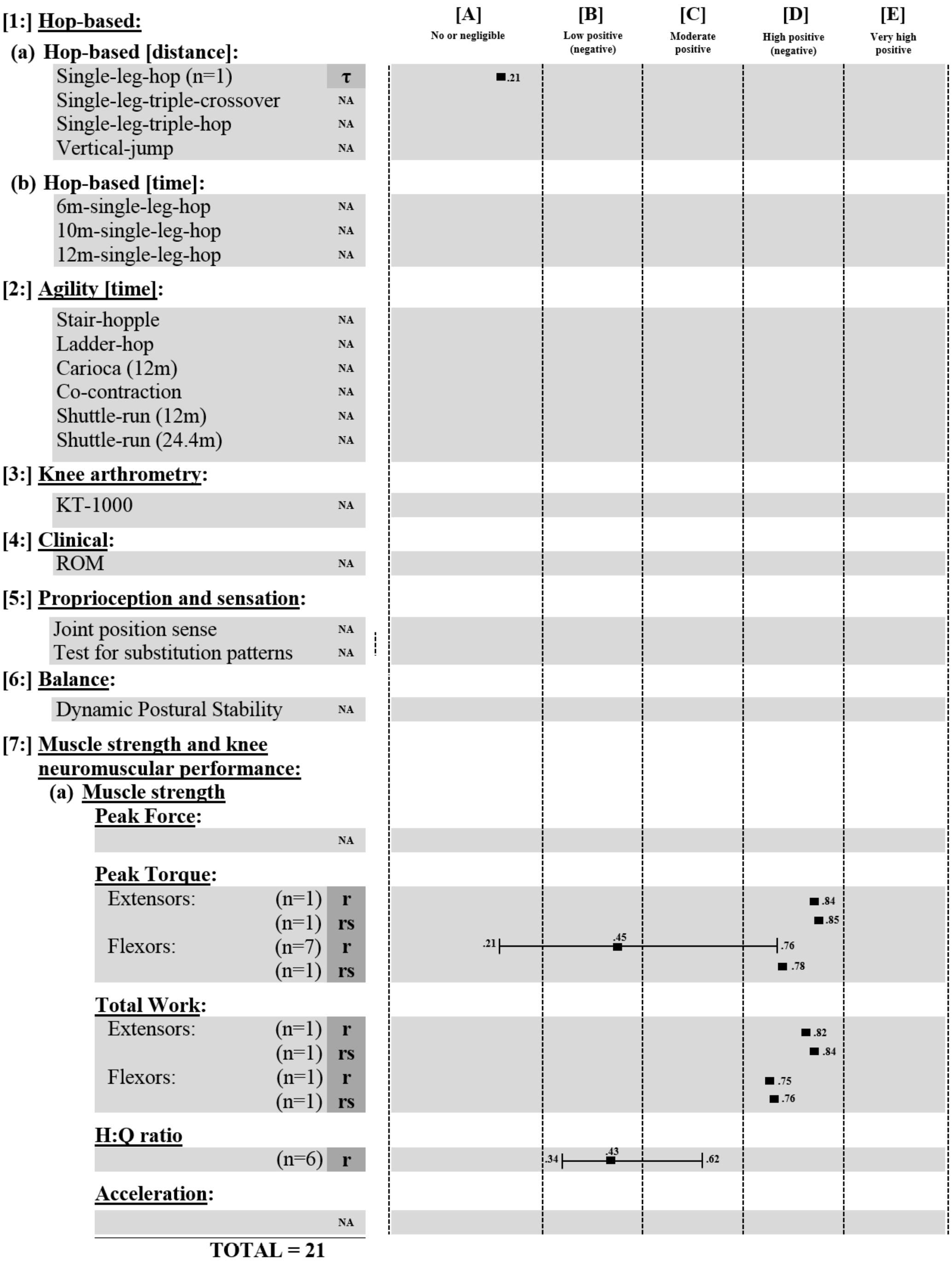
From this total of 388 correlations, 43 correlations were found for ACLD individuals and the remaining 345 correlations for ACLR individuals. As previously discussed, C-BOMs were categorised **(**see **FIGURE 9**; p. 138**)** and alongside side these categories, all significant correlations ($p< 0.05$) coefficients (n = 338) **(TABLE 11**; p. 140**)** were represented in accordance with Hinkle et al., (2003) interpretations, strength of relationships and classification of correlation ('non or negligible', 'low, 'moderate', 'high' and 'very high') **(**see **TABLE 6**; p. 126**)**. For example, a reported relationship between Single-Leg Hop for distance (a C-BOM) versus IKDC (a P-BOM) reported an r = 0.67 interaction. In line with Hinkle et al., (2003), this relationship would be described as a 'positive' and 'moderate' correlation/relationship. This process was completed for all 388 correlation found **(APPENDIX 7**; p. 515**)**.

The outcome of the Systematic Review in terms of the relationships found between P-BOM and C-BOM outcomes is illustrated on **FIGURE 10** (p. 142 to 143) for **[A]** ACLD and **[B]** ACLR, respectively. Where appropriate, separate range values for the knee flexors and knee extensors are reported. In the latter, it is not seen specifically which P-BOMs are correlated within the clinician-based categories (as determined from the systematic reviewing process of classifying C-BOMs **(see FIGURE 11**; p. 145**)** and their descriptions as above).

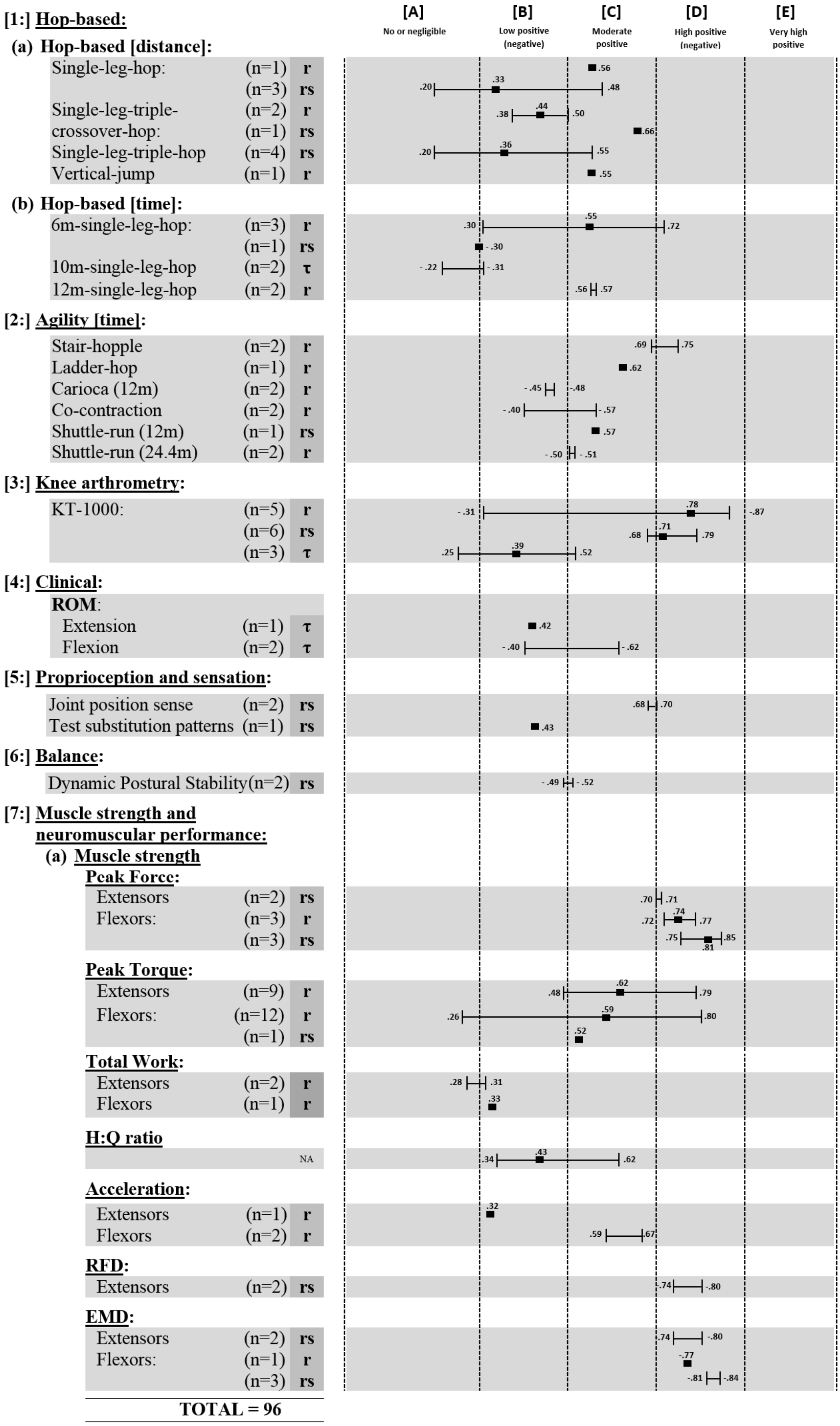
[40] n = Number of correlation coefficients found for ACLD individuals.

TABLE 11 - Reported number of significant (p< 0.05) and non-significant (p> 0.06) correlations found within classification of C-BOMs. **NOTE**: ACLD and ACLR individuals' values combined.

	C-BOM category/ outcome measure	Total no. correlations	No. of non-significant (p> 0.05) correlations
1.	**Hop-based test:**		
	(a) Hop (distance)	**42**	29 (69.05%)
	(b) Timed (distance)	**13**	5 (38.46%)
2.	**Agility-based**	**17**	7 (41.18%)
3.	**Knee stability**	**100**	86 (86%)
4.	**Clinical**	**50**	47 (94%)
5.	**Proprioception and sensation**	**15**	12 (80%)
6.	**Balance**	**4**	2 (50%)
7.	**Dynamometry:**		
	(a) Acceleration:		
	Extensors	**5**	2 (40%)
	Flexors	**5**	1 (20%)
	(b) Deceleration:		
	Extensors	**3**	3 (100%)
	Flexors	**3**	3 (100%)
	(c) H:Q	**9**	3 (33.33%)
	(d) Peak Force (PF):		
	Extensors	**2**	0 (0%)
	Flexors	**7**	2 (28.57%)
	(e) Peak Torque (PT):		
	Extensors	**24**	12 (50%)
	Flexors	**44**	23 (52.27%)
	(f) Total Work (TW):		
	Extensors	**18**	14 (77.78%)
	Flexors	**19**	16 (84.21%)
8.	**Neuromuscular:**		
	(a) Electromechanical Delay (EMD):		
	Extensors	**2**	0 (0%)
	Flexors	**4**	4 (100%)
	(b) Rate of force development (RFD):		
	Extensors	**2**	0 (0%)
	Flexors	**0**	0 (0%)
	TOTAL:	**388**	**271**


[1:] Hop-based:
(a) Hop-based [distance]:
Single-leg-hop (n=1) τ
Single-leg-triple-crossover NA
Single-leg-triple-hop NA
Vertical-jump NA
(b) Hop-based [time]:
6m-single-leg-hop NA
10m-single-leg-hop NA
12m-single-leg-hop NA
[2:] Agility [time]:
Stair-hopple NA
Ladder-hop NA
Carioca (12m) NA
Co-contraction NA
Shuttle-run (12m) NA
Shuttle-run (24.4m) NA
[3:] Knee arthrometry:
KT-1000 NA
[4:] Clinical:
ROM NA
[5:] Proprioception and sensation:
Joint position sense NA
Test for substitution patterns NA
[6:] Balance:
Dynamic Postural Stability NA
[7:] Muscle strength and knee neuromuscular performance:
(a) Muscle strength
Peak Force:
NA
Peak Torque:
Extensors: (n=1) r
(n=1) rs
Flexors: (n=7) r
(n=1) rs
Total Work:
Extensors: (n=1) r
(n=1) rs
Flexors: (n=1) r
(n=1) rs
H:Q ratio
(n=6) r
Acceleration:
NA
TOTAL = 21
[A]
No or negligible
[B]
Low positive (negative)
[C]
Moderate positive
[D]
High positive (negative)
[E]
Very high positive
.21
.84
.85
.21
.45
.76
.78
.82
.84
.75
.76
.34
.43
.62

[A] ACLD


[1:] Hop-based:
(a) Hop-based [distance]:
Single-leg-hop: (n=1) r
(n=3) rs
Single-leg-triple-crossover-hop: (n=2) r
(n=1) rs
Single-leg-triple-hop (n=4) rs
Vertical-jump (n=1) r
(b) Hop-based [time]:
6m-single-leg-hop: (n=3) r
(n=1) rs
10m-single-leg-hop (n=2) τ
12m-single-leg-hop (n=2) r
[2:] Agility [time]:
Stair-hopple (n=2) r
Ladder-hop (n=1) r
Carioca (12m) (n=2) r
Co-contraction (n=2) r
Shuttle-run (12m) (n=1) rs
Shuttle-run (24.4m) (n=2) r
[3:] Knee arthrometry:
KT-1000: (n=5) r
(n=6) rs
(n=3) τ
[4:] Clinical:
ROM:
Extension (n=1) τ
Flexion (n=2) τ
[5:] Proprioception and sensation:
Joint position sense (n=2) rs
Test substitution patterns (n=1) rs
[6:] Balance:
Dynamic Postural Stability(n=2) rs
[7:] Muscle strength and neuromuscular performance:
(a) Muscle strength
Peak Force:
Extensors (n=2) rs
Flexors: (n=3) r
(n=3) rs
Peak Torque:
Extensors (n=9) r
Flexors: (n=12) r
(n=1) rs
Total Work:
Extensors (n=2) r
Flexors (n=1) r
H:Q ratio
NA
Acceleration:
Extensors (n=1) r
Flexors (n=2) r
RFD:
Extensors (n=2) rs
EMD:
Extensors (n=2) rs
Flexors: (n=1) r
(n=3) rs
TOTAL = 96
[A]
No or negligible
[B]
Low positive (negative)
[C]
Moderate positive
[D]
High positive (negative)
[E]
Very high positive
.56
.20 .33 .48
.38 .44 .50
.66
.20 .36 .55
.55
.30 .55 .72
-.30
-.22 -.31
.56 .57
.69 .75
.62
-.45 -.48
-.40 -.57
.57
-.50 -.51
-.31 .78 -.87
.68 .71 .79
.25 .39 .52
.42
-.40 -.62
.68 .70
.43
-.49 -.52
.70 .71
.72 .74 .77
.75 .81 .85
.48 .62 .79
.26 .59 .80
.52
.28 .31
.33
.34 .43 .62
.32
.59 .67
-.74 -.80
.74 -.80
-.77
-.81 -.84

[B] ACLR

FIGURE 10 -[see ACLR and ACLD [previous pages] - All significant correlations ($p < 0.05$) found (n = 117) from the systematic reviewing of 18 studies concomitantly evaluating P-BOMs and C-BOMs (concomitantly) for all three types of correlation coefficient (r, rs, t) for **ACLD [A]** and **ACLR [B]** individuals using Hinkle et al., (2003) interpretations of strength of correlation coefficients.

3.5.1 - To establish the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly within clinical research and evaluated up to 5 years post-ACL injury for ACLD patients, or 5 years post-ACLR surgery

A total of 388 correlations were found to evaluate P-BOMs and C-BOMs concomitantly in ACLD/ACLR individuals[41]. A total of 271 (70%) reported correlations were found to be non-significant (at $p > 0.05$ level) for ACLD and ACLR individuals (20 and 251, respectively), and these were not included for analysis. The remaining 117 (30%) correlations were reported as significant ($p < 0.05$) for ACLD and ACLR individuals (21 and 96, respectively)**.** The low number of significant correlations ($p < 0.05$) found (117 versus 271) alone gives interesting insight towards describing an initial outcome for this study with approximately 43% of all correlation coefficients not reporting statistically significant interactions at a significance level of $p < 0.05$. From this point, only significant correlations/relationships ($p < 0.05$) are considered relevant for answering the proposed research questions.

Further, as regards the interpretation of correlation coefficients that may indicate statistically significant (at $p < 0.05$) and potential clinical relevance (at $r \geq 0.70$ level[42]), suggested by correlation coefficients within 'high' or 'very high' categories (see Hinkle et al., 2003), only a small percentage of the 117 correlation fulfilling the $p < 0.05$ and $r \geq 0.70$ level criteria, were found (36/117 [31%)] **(TABLE 12)**. Within these, several P-BOMs (Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance profile) were statistically significant ($p < 0.05$) and further demonstrated potential clinical relevance ($r \geq 0.70$) to a few C-BOMs (Single-Leg Hop for distance [6m-timed]), Stair-hopple test (timed), ATFD, PF, PT, TW, and EMD)) for both ACLD and ACLR individuals.

One study reported relationships amongst Bi-POMs[43] (a P-BOM) and several C-BOMs (PF, EMD, and ATFD[44]) within a relatively close period to ACLR surgery and at over 10 weeks of rehabilitation (Gleeson et al., 2008). The Bi-POMs sub-scales (anxious-composed and confused-

[41] For a full description of the reported relationships between P-BOMs and C-BOMs, for all the correlations found (n = 388), consult **APPENDIX 7 (**p. 515).

[42] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

[43] Bipolar Profile of Mood States (Bi-POMs).
[44] Anterior Tibio-Femoral Displacement (ATFD).

clear headed) at 8 and 10 weeks post-ACLR surgery were all negatively correlated with PF (anxious-composed: $r = 0.77$, $p < 0.05$; confused-clear headed: $r = 0.72$ to 0.74, $p < 0.05$). Similarly, the remaining Bi-POMs sub-scales (depressed-elated, hostile-agreeable, tired-energetic) were negatively correlated with EMD (depressed-elated: $r = -0.77$, $p < 0.05$) and ATFD ($r = 0.72$ to 0.87, $p < 0.01$ [see **TABLE 12** [p. 146] for sub-scales]). For a similar P-BOM, the ERAIQ associated with the discouraged and pain sub-scales were both positively correlated with ATFD ($rs = -0.79$, $p < 0.01$, $rs = 0.78$, $p < 0.01$), however, the ERAIQ (discouraged) sub-scale was positively correlated with PF ($rs = 0.75$, $p < 0.05$).

Within the same Study (Gleeson et al., 2008), the Performance Profile was evaluated with the same C-BOMs (PF, EMD, and ATFD). The Performance Profile at pre-surgery, and at 6 and 10 weeks post-ACLR surgery was shown to be negatively correlated with EMD ($rs = 0.81$ to 0.84, $p < 0.01$). With regards to ATFD, the Performance Profile was significantly and positively correlated at 8 weeks ($rs = 0.72$, $p < 0.05$) and again at 10 weeks post-ACLR surgery ($r = -0.70$, $p < 0.05$). Interestingly, the Performance Profile versus PF at pre-surgery and at 8 weeks post-ACLR surgery was considerably different; as at pre-surgery, Performance Profile was positively correlated with PF ($r = 0.85$, $p < 0.05$), whilst at 8 weeks post-ACLR surgery, this relationship was negatively related ($r = -0.82$, $p < 0.05$).

With the more conventional P-BOMs used within ACL practice, the Lysholm ($r = 0.76$ to 0.84, $p < 0.01$; $rs = 0.78$ to 0.85, $p < 0.01$) and Cincinnati ($r = 0.70$ to 0.78, $p < 0.01$) were both shown to positively correlate with PT, using multiple isokinetic protocols and assessed at fixed knee angle dynamometry measurements, for both the knee flexors and extensors, evaluated at differing timeframes (Lysholm = 59 months' post-ACLR; Cincinnati = [ACLD = 3 months' post-injury; ACLR= [10-14 months' post-ACLR]. Similarly, TW was also shown to be significantly and positively correlated with the Lysholm ($r = 0.76$ to 0.84, $p < 0.01$; $rs = 0.78$ to 0.85, $p < 0.01$) at 5 years post-ACLR surgery.

In two studies (Wilk et al. 1994; Seto et al. 1988) evaluating the relationship between TW, the Noyes (modified) ($r = 0.71$, $p < 0.01$) and FAS ($r = 0.74$ to 0.79, $p < 0.01$; $rs = 0.74$, $p < 0.01$) the Noyes and FAS were both shown to have positive correlations with TW for the knee flexors and knee extensors, at 6 months' and 5 years' post-ACLR surgery, respectively.

In the final study, Goh et al. (1997) evaluated the relationship between the VAS (satisfaction) and Noyes (modified) with the timed 6m single-leg-hop ($r = 0.72$, $p < 0.05$) and Stair-Hopple (timed test) ($r = 0.72$, $p < 0.05$), respectively, between 24 to 48 months' post-ACLR surgery. The VAS (satisfaction) and Noyes (modified) P-BOMs are suggestive of a positive high correlation with the 6m Single-Leg Hop for distance and Stairs-Hopple C-BOMs evaluated by time.

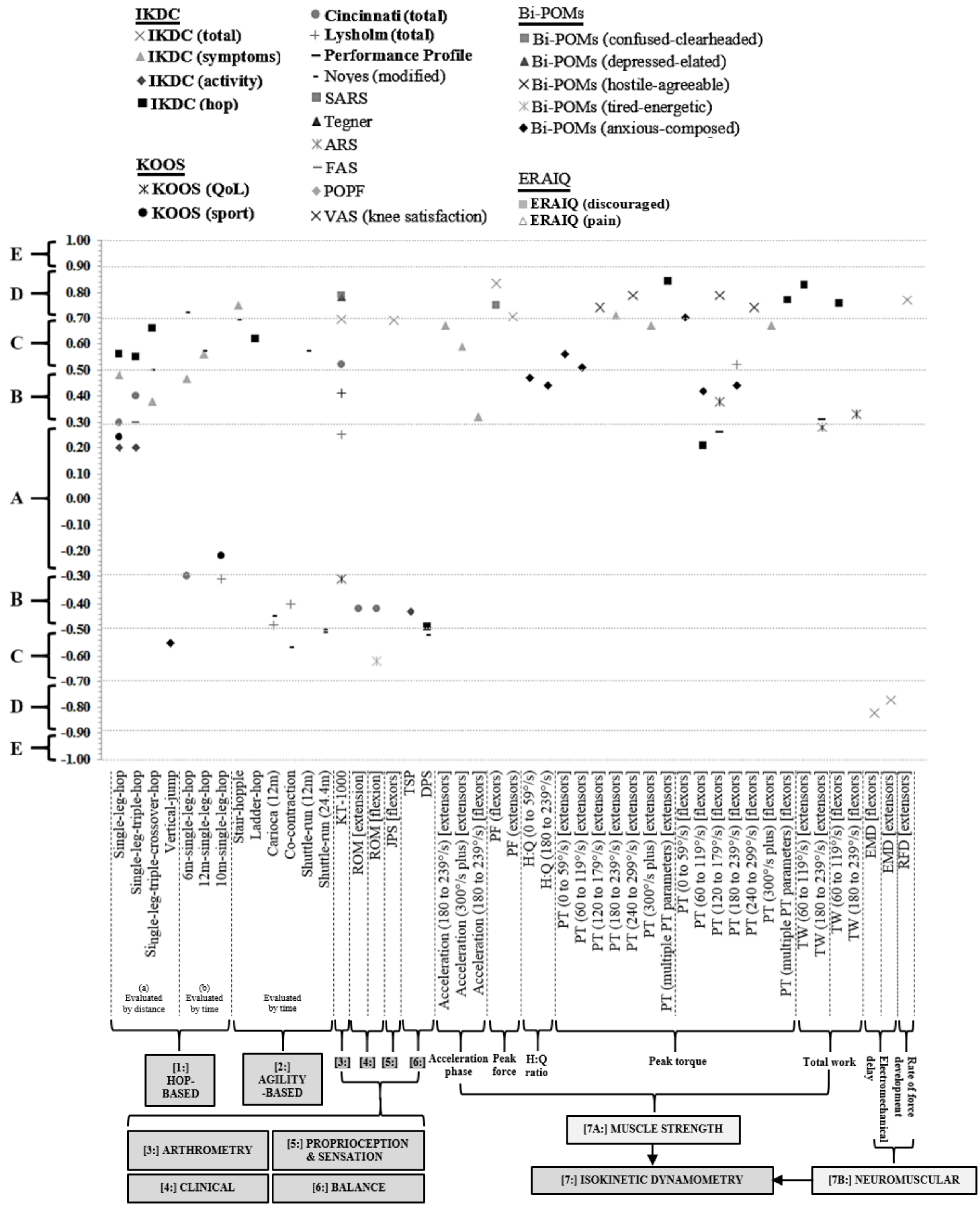


FIGURE 11 - Scatter graph showing statistically significant (p< 0.05) and clinically relevant (r≥ 0.70) correlations (based on Hinkle et al. 2003 interpretation) amongst P-BOMs and C-BOMs evaluated concomitantly. **NOTE**: The mean correlational values for the Cincinnati (n = 22), Lysholm (n = 8), Modified Noyes (n = 2), and Performance Profile (n = 18) have been combined (No range scores shown).

TABLE 12 - All correlation coefficients found to be statistically significant ($p < 0.05$) and potentially clinically relevant ($r \geq 0.70$) evaluating P-BOM and C-BOM concomitantly for ACLD and ACLR individuals. **NOTE**: Study evaluation points (months from ACL injury to evaluation time frame(s), or months from ACLR injury to ACLR surgery).

Study	Population	P-BOM	vs.	C-BOM	Correlation Coefficient	Correlation Coefficient Value	Evaluation (months)
Gleeson et al. 2008	ACLR	Bi-POMs (anxious-composed)	vs.	PF	r =	-0.77†	2
Gleeson et al. 2008	ACLR	Bi-POMs (confused-clear headed)	vs.	PF	r =	-0.74†	2.5
Gleeson et al. 2008	ACLR	Bi-POMs (confused-clear headed)	vs.	PF	r =	-0.72†	2.5
Gleeson et al. 2008	ACLR	Bi-POMs (depressed-elated)	vs.	EMD	r =	-0.77†	2
Gleeson et al. 2008	ACLR	Bi-POMs (depressed-elated)	vs.	ATFD	r =	-0.85‡	22
Gleeson et al. 2008	ACLR	Bi-POMs (hostile-agreeable)	vs.	ATFD	r =	-0.72†	2
Gleeson et al. 2008	ACLR	Bi-POMs (tired-energetic)	vs.	ATFD	r =	-0.87‡	2
Bryant et al. 2008a	ACLD	Cincinnati	vs.	PT (Flex. at 30°-20°)	r =	0.70‡	3
Bryant et al. 2008b	ACLR	Cincinnati	vs.	PT (Flex. at 40°-30°)	r =	0.74‡	10-14
Bryant et al. 2008b	ACLR	Cincinnati	vs.	PT (Flex. at 50°-40°)	r =	0.78‡	10-14
Bryant et al. 2008b	ACLR	Cincinnati	vs.	PT (Flex. at 20°-10°)	r =	0.80⁞	10-14
Gleeson et al. 2008	ACLR	ERAIQ (discouraged)	vs.	ATFD	r =	0.79†	2
Gleeson et al. 2008	ACLR	ERAIQ (discouraged)	vs.	PF	r =	-0.75†	2
Gleeson et al. 2008	ACLR	ERAIQ (Pain)	vs.	ATFD	rs =	0.78†	2.5
Seto et al. 1988	ACLR	FAS	vs.	PT (Ext. at 120°/s)	rs =	0.74†	58
Seto et al. 1988	ACLR	FAS	vs.	PT (Flex. at 120°/s)	r =	0.79‡	58
Seto et al. 1988	ACLR	FAS	vs.	PT (Ext. at 240°/s)	r =	0.79	58
Seto et al. 1988	ACLR	FAS	vs.	PT (Flex. at 240°/s)	r =	0.74†	58
Goh et al. 1997	ACLR	VAS (satisfaction)	vs.	Hop (6m [timed])	r =	0.72†	24-48

Study	Population	P-BOM	vs.	C-BOM	Correlation Coefficient	Correlation Coefficient Value	Evaluation (months)
Kannus, 1988	ACLD	Lysholm	vs.	TW (60°/s)	r =	0.75‡	59
Kannus, 1988	ACLD	Lysholm	vs.	TW (60°/s)	r =	0.78‡	59
Kannus, 1988	ACLD	Lysholm	vs.	TW (60°/s)	r =	0.82‡	59
Kannus, 1988	ACLD	Lysholm	vs.	TW (60°/s)	rs =	0.84‡	59
Kannus, 1988	ACLD	Lysholm	vs.	PT (Flex. at 60°/s; post 1 min rest; Flex. at 180°/s)	r =	0.76‡	59
Kannus, 1988	ACLD	Lysholm	vs.	PT (Flex. at 60°/s; post 1 min rest; Flex. at 180°/s)	rs =	0.78‡	59
Kannus, 1988	ACLD	Lysholm	vs.	PT (Ext. at 60°/s; post 1 min rest; Ext. at 180°/s)	r =	0.84‡	59
Kannus, 1988	ACLD	Lysholm	vs.	PT (Ext. at 60°/s; post 1 min rest; Ext. at 180°/s)	rs =	0.85‡	59
Wilk et al. 1994	ACLR	Noyes (modified)	vs.	PT (Ext. at 180°/s)	r =	0.71‡	6
Goh et al. 1997	ACLR	Noyes (modified)	vs.	Stair-Hopple-test (timed)	rs =	0.75†	24-48
Gleeson et al. 2008	ACLR	Performance profile	vs.	PF	r =	0.85‡	- 0.5
Gleeson et al. 2008	ACLR	Performance profile	vs.	ATFD	r =	0.70†	2.5
Gleeson et al. 2008	ACLR	Performance profile	vs.	ATFD	rs =	0.72†	2
Gleeson et al. 2008	ACLR	Performance profile	vs.	EMD	rs =	-0.84‡	2.5
Gleeson et al. 2008	ACLR	Performance profile	vs.	EMD	rs =	-0.82‡	- 0.5
Gleeson et al. 2008	ACLR	Performance profile	vs.	EMD	rs =	-0.81‡	2
Gleeson et al. 2008	ACLR	Performance profile	vs.	PF	rs =	-0.82‡	2

3.5.2 - To establish, more specifically, whether the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly occurs at differing time-points across an ACL rehabilitation programme (0-24 weeks)

The time from the participant's injury to surgery for the ACLR studies, and the time from injury to study evaluations for ACLD participants differed considerably **(FIGURE 12**; p. 149**)**. The presented data were reported in days, weeks, and in many cases, in months. As such, all values were computed where possible for the time from injury to surgery, and for the time from injury to evaluation in months, for easier comparison. From the 23 ACLR studies, only 12 studies reported the time from the participant's injury to surgery, thus, a mean of 18.8 ± 8.6 months was calculated, however, 11 studies did not report these values; therefore, the time from injury to surgery was not known for 440 participants.

With regards to ACLD participants, the time from injury to time of evaluations was not available as participants were either waiting for surgery or were considered to be participants who were coping with an ACLD knee. However, for both ACLR and ACLD studies, the time from injury to surgery and following evaluations were mixed, and at times these values varied within the identified studies. For example, four studies (Bryant et al., 2008b; Goh and Boyle, 1997; Kong et al., 2012; Reinke et al., 2011) did not report the evaluation time-points for participants precisely, but rather reported evaluation points within two time frames. For example, in Bryant and colleagues (2008b), the evaluation timeframe is reported as between six to nine months post-surgery. Six studies conducted several evaluations at different post-surgery timeframes. These evaluation timeframes varied considerably from 2, 6, 8 and 10 weeks post-surgery (Yates et al., 2016; Gleeson et al., 2008), to 3, 6, 12 and 24 months post-surgery (Chia and Chok, 1999; Risberg et al., 1999b; Risberg et al., 1999c; Holm et al., 2000). In the study by Li et al., (1996), the time from injury to study evaluation was not reported, however, from the study design and the intervention conducted it was estimated that patient evaluation was performed pre-operatively, and again at 8 weeks post-surgery. In the study conducted by Neeb et al., (1997) it was not possible to ascertain the time from injury to the time of the study evaluation as this information was not reported.

To further complicate matters, Goh et al. (1997) - for one study as an example - reported that the evaluation time from ACLR surgery for participants ranged from 24 to 48 months. These vastly differing time points make it difficult to understand the association or discordance between P-BOMs and C-BOMs evaluated concomitantly across an ACL rehabilitation programme. Unfortunately, the outcome of this Systematic Review reports insufficient correlational information which is both significant and clinically relevant occurring with sufficient frequency across the rehabilitation phases (0-24 weeks) to accurately describe the association/discordance between P-BOMs and C-BOMs within this period.

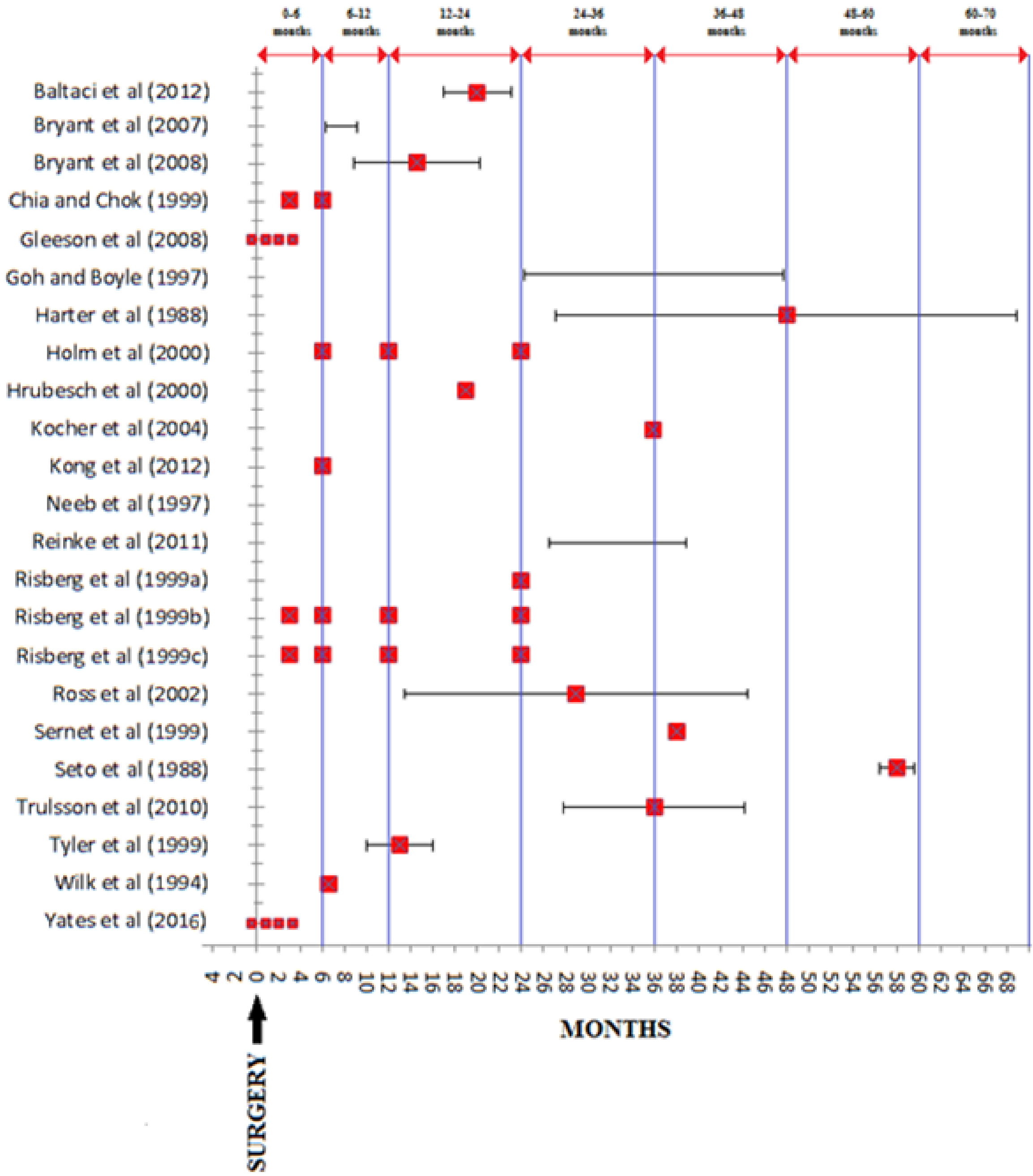


FIGURE 12 - Time from ACLR surgery to study evaluation for each study (Means ± SD, where reported). <u>**NOTE**</u>: Time from ACL injury to study evaluation not shown (Source: Author's own diagram).

3.5.3 - To identify the long-term association and discordance between P-BOMs and C-BOMs evaluated at 1 year and up to 5 years' post-injury for ACLD, or 1 year and up to 5 years' post-ACLR surgery

Four studies for ACLR individuals were evaluated at 1 year and up to 5 years' post-ACLR surgery (Bryant et al., 2008a; Goh et al., 1997; Seto et al., 1988; Kannus, 1998), 10 to 14 months (approximately 1 year post-ACLR) [r = 0.74 to 0.80, p< 0.05 to 0.01], 24 to 48 months (2 to 4 years post-ACLR surgery) [r = 0.72, p< 0.05; rs = 0.75, p< 0.01], and 58 months (approximately 5 years post-ACLR surgery) [r = 0.74 to 0.79, $p < 0.05$ to 0.01; rs = 0.74, $p < 0.05$], respectively. Within these time-points, only a few P-BOMs (VAS [satisfaction], Noyes [modified], Cincinnati, and FAS) were concomitantly correlated with two-functional performance-based outcomes (Single-Leg Hop for distance over 6m distance [timed], and Stairs Hopple test [also timed]) and dynamometry outcomes of PT, for the knee flexors and knee extensors. For the only remaining study (Kannus, 1988), the authors evaluated Lysholm (a P-BOM) versus PT (r = 0.76 to 0.84, $p < 0.01$; rs = 0.78 to 0.85, $p < 0.01$) and TW (r = 0.75 to 0.82, $p < 0.01$; rs = 0.84, $p < 0.01$) at 59 weeks' (approximately 5 years) post-ACL injury. In view of the above, it would appear that there are simply not enough correlations to elucidate these relationships and allow this research question to be answered.

3.6 - Methodological Quality Assessment

The methodological quality assessment was conducted using a modified version of the 'Cochrane Methods Group on Screening and Diagnostic Tests Methodology' [abbreviated: CM] (Devillé et al., 2002). However, in accordance with Gokeler et al., (2012), a modified version of CM was used to assess each study. This modified version (as suggested by Gokeler et al., 2012) was more appropriate to the type and design of studies presented in this review and, thus, was implemented. The following criteria were modified from the original CM version, and as recommended, questions one to four were replaced by the Oxford Centre for Evidence-based Medicine (www.cebm.net) to score the level of evidence from 1 to 5 (high score to low score, respectively). The maximum score of the modified CM was 16 points. The methodological quality assessment of the studies included (n = 30) in the review is presented in **TABLE 13** (p. 151).

The mean of the methodological quality score was 9.3 ± 1.5 (Mean ± SD) on the CM checklist. Common weaknesses in the checklist's methodological design were lack of reliability of testing reported from the majority of studies included within the review (only four studies reported to assess reliability), incomplete description of patient's demographic data, limited descriptive data reported for the time from injury to ACLR surgery or time of injury to studies/evaluations. All of the studies had a low level of evidence as assessed using the Oxford Centre for Evidence-based Medicine Levels of Evidence. None of the reviewed studies scored higher than level 2 of evidence with a 1.24 ± 0.44 (Mean ± SD) score. As reported by Gokeler et al., (2012), a combination of the CM assessment scale and the Oxford Centre of Evidence levels was necessary, as at present a specific checklist to assess the methodological assessment with the design of the studies included in this review is not currently available. In addition, the authors note that this modified scoring system is arbitrary; however, using this assessment scale was necessary to compare the included studies (Gokeler et al., 2012).

TABLE 13 - Methodological quality of all the studies included in the Systematic Review using the modified Cochrane Methods Group on Screening and Diagnostic Tests Methodology (n = 30).

AUTHORS/STUDY	DESIGN[45]	EVIDENCE[46]	CRITERIA[47]	SETTING[48]	TESTS/ REFERRAL[49]	INJURY/ SURGERY EVALUATION[50]	CO-MORBID OR TYPE OF SURGERY[51]	DEMOGRAPHIC[52]	PERMIT REPLICATE[53]	STATISTICAL ANALYSIS[54]	RELIABILITY[55]	% MISSING[56]	TOTAL
Yates et al. (2016)	1	2	1	1	1	1	1	1	1	1	0	1	12
Gleeson et al. (2008)	1	2	1	1	1	1	1	1	1	1	0	1	12
Seto et al. (1988)	1	2	1	1	1	1	1	1	1	1	0	1	12
Baltaci et al. (2012)	1	2	0	1	1	1	1	1	1	1	0	1	11
Neeb et al. (1997)	1	1	1	1	1	1	1	1	1	1	1	0	11
Li et al. (1996)	1	1	1	1	1	1	1	1	1	1	0	1	11
Park et al. (2010)	1	1	1	1	1	1	1	1	1	1	0	0	10
Bryant et al. (2008a)	0	1	1	0	1	1	1	1	1	1	1	1	10
Bryant et al. (2008a)	0	1	1	1	1	1	1	1	1	1	0	1	10
Kocher et al. (2004)	0	2	1	1	1	1	1	1	0	1	1	0	10
Holm et al. (2000)	1	1	1	0	1	1	1	1	1	1	0	1	10
Risberg et al. (1999a)	1	1	1	0	1	1	1	1	1	1	0	1	10
Risberg et al. (1999b)	1	1	1	0	1	1	1	1	1	1	0	1	10
Kong et al. (2012)	0	2	0	0	1	1	1	1	1	1	0	1	9
Reinke et al. (2011)	0	1	1	1	1	1	1	0	1	1	0	1	9
Trulsson et al. (2010)	0	1	1	0	1	1	1	1	1	1	0	1	9
Chia and Chok (1999)	1	2	0	0	0	1	1	1	1	1	0	1	9
Borsa et al. (1998)	0	1	0	1	1	1	1	1	1	0	1	1	9
Goh & Boyle, (1997)	0	1	1	1	1	0	1	1	1	1	0	1	9
Snyder-Mackler et al. (1997)	0	1	1	1	1	1	1	0	1	0	1	1	9
Lephart et al. (1992)	0	1	1	1	1	1	1	1	1	1	0	0	9
Ross et al. (2002)	0	1	1	1	1	1	1	1	1	0	0	0	8
Sernert et al. (1999)	0	1	1	1	1	1	1	1	1	0	0	0	8
Tyler et al. (1999)	1	1	0	0	1	1	1	1	0	1	0	1	8
Wilk et al. (1994)	0	1	0	0	1	1	1	1	1	1	0	1	8
Harter et al. (1998)	0	1	0	1	1	1	1	1	1	1	0	0	8
Hrubesch et al. (2000)	0	1	1	0	1	1	1	1	0	0	0	1	7
Risberg et al. (1999a)	0	1	0	1	1	0	1	0	1	0	1	1	7
Harilainen et al. (1995)	1	1	0	0	1	1	1	1	0	0	0	1	7
Kannus (1988)	1	1	0	0	1	1	1	0	1	1	0	0	7

TOTAL = 9.3 ± 1.5 (maximum score of 16)

[45] Prospective (=1 point), or retrospective series (=0 point)
[46] Oxford Centre for Evidence-Based Medicine: Level of Evidence (Level, L1 = 5 points; L2 = 4 points; L3 = 3 points; L4 = 2 points; L5 = 1 point)
[47] Inclusion and exclusion criteria reported (= 1 point)
[48] Enough information to identify setting (=1 point)
[49] Details given about clinical and other diagnostic information as to which index test is being evaluated: symptomatic or asymptomatic (=1 point)
[50] Mean or median, and SD reported (=1 point)
[51] Details given (=1 point)
[52] Age (mean or median. and SD or range), and gender reported (=1 point)
[53] Test device, Patient positioning, Speed tested, number of trials (two or more items =1 point)
[54] Details given on mean or median, SD or CI and p value for P-BOMs and C-BOMs and p-value correlation (=1 point)
[55] Reliability reported (=1 point)
[56] All included subjects measured and, if appropriate, missing data or withdrawals from study reported or explained (=1 point)

3.7 - Discussion

A Systematic Review with a meta-analysis was originally proposed within this study to evaluate the strength of the relationship between P-BOMs and C-BOMs in patients with ACL deficiency, evaluated up to 5 years' post-ACL injury, or 5 years' post-ACLR surgery. This Systematic Review was a first attempt to systematically evaluate the P-BOMs and C-BOMs concomitantly with ACL-deficient populations. It was the intent of this study to perform a meta-analysis, however, due to the heterogeneous nature of the studies found in terms of the wide variety of outcome measures (both P-BOMs and C-BOMs found) and the nature of the study designs, a meta-analysis of the full set of studies was deemed impossible, and meta-analyses on a small number of sub-sets was considered to be unworthy. A narrative synthesis of all studies was therefore performed instead. The purpose of this discussion is consequently to critically evaluate and summarise the findings and clinical implications of the studies within the systematic review.

Most striking from the outset was the heterogeneity of P-BOMs and C-BOMs found during the reviewing process, twenty-six P-BOMs and forty-six C-BOMs illustrated the diversity of outcome measures in assessing study outcomes, indeed, the studies were mostly non-comparable with no same P-BOMs consistently being evaluated with the same C-BOMs. Moreover, of the 388 correlations found from the concomitant evaluation of P-BOMs and C-BOMs, only 117 (117/388: 30%) were found to be statistically significant (at $p > 0.05$ level), with only a further 36 (36/388: 11%) having potential clinical relevance (at $r \geq 0.70$ level). These low significant/non-significant correlations (117 versus 271), and the small number of correlations demonstrating clinical relevance ($r \geq 0.70 = 36$) gives interesting insight towards describing an initial outcome for this study with approximately 91% of all correlation coefficients not reporting any statistical significance or clinical relevance. Importantly, there would also be a 5% chance of relationships being reported that could have occurred randomly with no relationships actually existing, therefore, the outcome of this study should be considered with caution. The extent and strength of relationships among P-BOMs and C-BOMs cannot therefore be judged with certainty and remains relatively speculative; further investigation is thus warranted.

Given that only some statistically-significant correlations were found among P-BOMs and C-BOMs, that they were not strong enough to be clinically relevant, that they lacked relevance across the rehabilitation period of 24 weeks, and were hardly evident at 1 year and up to 5 years' post-injury, and 1 year and up to 5 years' post-ACLR surgery, the four research questions (see p. 113) will not be addressed separately, but collectively. Several explanations have been theorised for the lack of relationships between P-BOMs and C-BOMs and the different relationships that do exist are difficult to interpret, requiring speculation on an individual basis (Pua et al., 2008). This may be partly due to inconsistencies in the subject population and pathologic condition, broad differences in the non-standardised approaches to the methodological testing of patients, the wide variety of equipment used to assess outcomes (i.e., dynamometry to various hop-based tests etc.) and the different methods of assessing test results (Wilk et al., 1994). Further, differences may be associated with measurement error, the extent to which P-BOMs adequately measure what they say they are measuring, and the relationship between C-BOMs and the accurate physical demands associated with Activities of Daily Living (ADL) (Hoeymans et al., 1996; Rejeski et al., 1995).

Notwithstanding the above, another explanation could be the fact that each P-BOM and C-BOM outcome quantifies different aspects of function and recovery that cannot be causally link (Akker-Scheek et al., 2008; Reid et al., 2007; Stratford and Kennedy, 2006; Fitzgerald et al., 2001), for example, a P-BOM will examine a patient's perceived disability, while a C-BOM, including clinical tests, will measure specific levels of impairment (Neeb et al., 1997). However, because disability can be consequence of impairment, it may be considered that a relationship could exist between the two with respect to severity of the impairment, but this remains unknown (Farzad et al., 2015). Similarly, correlational investigations assessing inter-correlation between different P-BOMs (i.e., IKDC versus KOOS) have also reported poor correlations (Anderson et al., 1993) and these comparison studies are often described as inappropriate (Hrubesch et al., 2000) since poor correlations may be due to different P-BOMs placing emphasis and weighting on different aspects of subjective and objective knee function when generating scores (Shaw et al., 2005). The limited evidence for the inter-correlation between C-BOMs (i.e., Single-Leg Hop for distance versus TW) have similarly reported to have poor to moderate relationships (Ahn et al., 2011; Eitzen et al., 2009; Herrington et al., 2003; Jarvela et al., 2002; Schmidt-Rohlfing et al., 2011; Shiraishi et al., 1996).

Importantly, the findings of this study may have implications for clinical practice. At this time, this study does not support the single use of any one P-BOM and/or C-BOMs across any stage of ACL rehabilitation or up to 5 years' post-ACL injury or post-ACLR surgery. Therefore, physiotherapists should ensure they do not devise a plan a patient rehabilitative regime based on a single specific outcome measure, it would in fact be necessary to deploy a series of P-BOM and C-BOM outcome measures in order to holistically evaluate patient outcomes (Lavoie et al., 2001).

With this said, there is insufficient correlational evidence in this study to support the proxy use of P-BOMs as efficient substitutes for more complex objective-derived (clinician-based) outcome measures. Furthermore, the absence of strong correlations and frequent linkage among P-BOM and C-BOM, evaluated concomitantly, further suggests that both P-BOMs and C-BOMs quantify different aspects of function and recovery that cannot be causally linked (Akker-Scheek et al., 2008; Reid et al., 2007). If strong relationships were to have been found amongst the candidate outcome measures, it could have led to a reduction in the number of P-BOMs and C-BOMs required to assess patient outcomes post-ACLR surgery in the future. This is particularly important for the thesis as whole, since at this time, it remains unknown which outcomes should be deployed post-

ACLR (Howe et al., 2012), therefore, the logical progression for future research would be to further evaluate a range of P-BOMs and C-BOMs concomitantly at 24 weeks of rehabilitation, as this could not be seen by the results of this systematic review.

Another important clinical implication could be related to the disassociation between P-BOMs and C-BOMs. This disassociation between P-BOM and C-BOM could imply to sub-optimal conditioning within rehabilitation therapy with the mismatching of patient-perceived capabilities to the objectively-derived measurements evaluated by C-BOMs (Terwee, Bouwmeester, van Elsland, de Vet, and Dekker, 2011), which to some extent may allow a more accurate discrimination of actual functional performance and executable capabilities. It is important for physiotherapists to be aware that if a patient's perception is mismatched to their actual function performance capabilities, this could increase the risk of further injury if the patient chooses to undertake activities they are not properly prepared for (Terwee et al., 2011); physiotherapists should therefore act appropriately to ensure this risk of further injury is minimised. As such, C-BOMs (providing an objective measurement of impairment) are not subject to a large degree of individual interpretation, and are more likely to be reliably measured across patient recovery (or across a study design), by different physiotherapists, and over time compared to P-BOMs (Velentgas et al., 2013). Thus, it could be reasoned that greater reliance on C-BOMs to justify potential clinical decisions regarding patient management and treatment planning is assumed (Copeland et al., 2008; Jette et al., 2009; Swinkels et al., 2011). Nevertheless, given recent concerns over the uncorroborated use P-BOMs (Zarins et al., 2005), clinical practitioners should be aware that subjective (P-BOMs) ratings of knee function are not a precise replacement for C-BOMs that indicate physical improvements in fitness and recovery (Michener, 2011; Valier and Kenneth, 2015).

With regard to the disassociation among P-BOMs and C-BOMs, if a patient's perception is mismatched with their actual function performance capabilities, this could potentially increase the risk of further injury if the patient chooses to undertake activities he or she was not properly prepared for (Terwee et al., 2011). Previous research (Yates et al., 2016), evaluated the Performance Profile versus C-BOMs (PF, EMD, RFD, and SMP-FE) at 2 weeks pre-ACLR surgery, and at 6, 8 and 10 weeks post-ACLR surgery. It was found that there was in fact a mismatch in patients' perceptions (Performance Profile) versus their actual physical performance (evaluated by C-BOMs), whereby a latency of two weeks was found. It could be speculated that over this period of time from ACLR surgery to 10 weeks' post-ACLR during rehabilitation, that participants had achieved limited experience of stressing or testing the capability of the injured knee joint, and had become habituated to the 'feel' of the injured leg. This type of compensatory effect may have led to a patient-perceived scaling of response that under-estimated the extent of inter-limb discrepancy of C-BOM capabilities prior to ACLR surgery. Therefore, Performance Profile responses might have been calibrated against patients' unrealistic self-perceived expectations post-

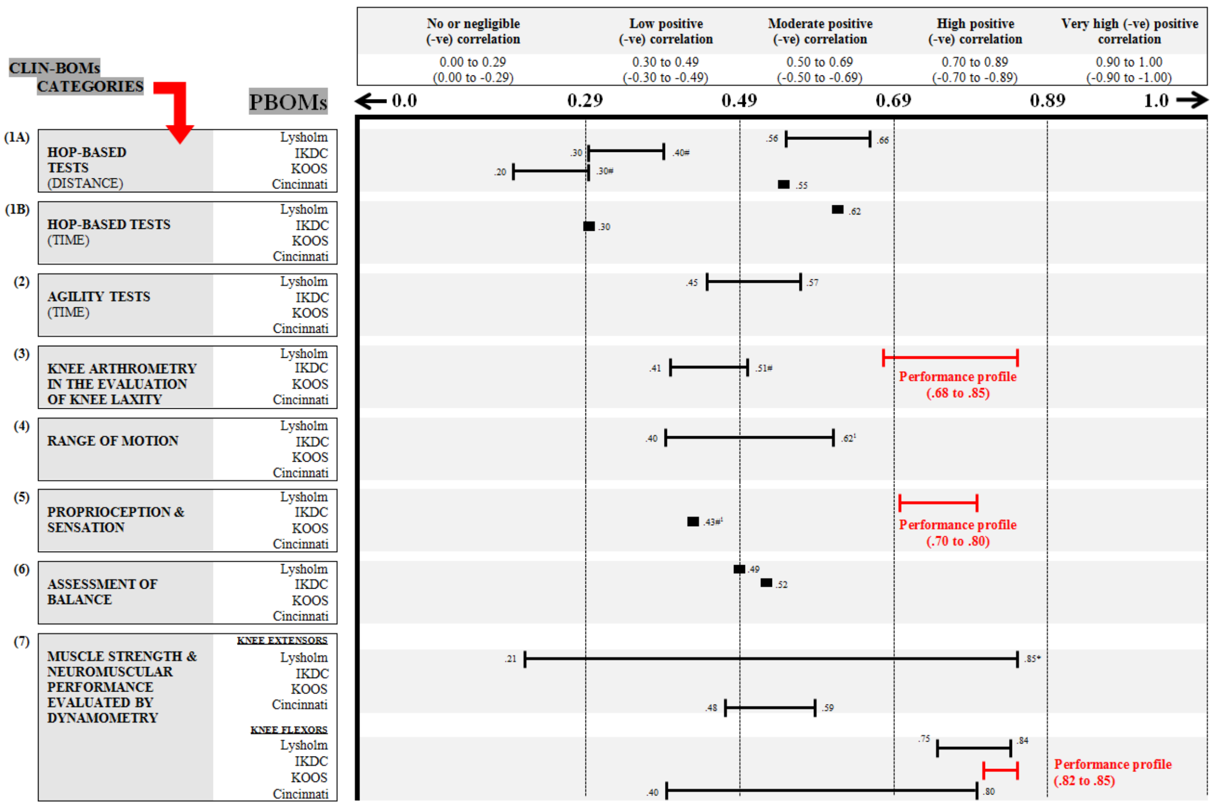
ACLR surgery (Yates et al., 2016). Importantly, clinicians should be aware that participants are likely to considerably miscalibrate their true capabilities and to perceive high levels of dysfunction over this initial period of rehabilitation. As such, any evidence of concomitant physical improvements occurring from pre-surgery levels might be delivered usefully to patients as feedback to reassure them of progress towards favourable clinical outcomes.

Nevertheless, P-BOMs are an important component in patient assessment, which have been reported to further elucidate and understand what is important to the patient (Michener, 2011) via a P-BOM-aligned approach, strengthening patient-centred care (Faller, 2003). Specifically, in ACL deficiency, at the present time, it remains unknown what outcome measures (P-BOM or C-BOMs) are necessary to effectively deliver a truly 'global' assessment of a patient following ACL injury (Howe et al., 2012). Thus, the consistent lack of statistically and clinically-relevant correlation between P-BOMs and C-BOMs highlights the challenges faced by clinicians and researchers. These include determining the minimum number of either P-BOMs or C-BOMs required to properly describe changes in functional or physical performance of patients during their rehabilitation, and importantly, the dilemma of whether P-BOMs or C-BOMs offer most validity (see Reiman and Manske, 2011).

A low correlation suggests that each outcome is assessing a different component of capability (that shares no variance with other relevant outcomes) and that, given the absence of gold standard outcomes to define a hierarchy of validity (Valier et al., 2015), information from all outcomes might be important and needed to capture a complete profile of functional or performance capabilities of individual patients. In the latter scenario, the limitations to the minimum clinical difference that might be properly detected with appropriate statistical confidence will depend on, and be limited by, the psychometric characteristics of the outcome measure with the poorest precision or sensitivity.

It is noteworthy that a P-BOM known as the Performance Profile was found to be consistently and in most instances highly correlated with several clinician-based methods of assessment **(**see **FIGURE 13** [p. 156]; correlational coefficient ranges highlighted in **RED)**. Here, correlation coefficient values ranged from rs = 0.68 to 0.85 ($p < 0.01$ to 0.05), moderate to high correlations, respectively (Hinkle et al., 2003). The Performance Profile did correlate unequivocally or more greatly with 3 of the 4 most traditional P-BOMs used within ACL assessments (IKDC, KOOS, Lysholm, and Cincinnati) It could be hypothesised that the fact that the Performance Profile equals or has greater relationships compared to these more traditional P-BOMs may be due to the construction and individualised nature of the Performance Profile which differs from the traditional P-BOMs.

For example, the patient constructing an individualised outcome measure (i.e., Performance Profile) is allowed to select his or her own issues, domains or concerns regarding which outcomes have personally been affected since the time of injury (Fitzpatrick et al., 1998). In doing so, the identified issues, domains or concerns selected by the patient would be potentially more meaningful than if they were answering a list of predetermined questions in a P-BOM (such as the KOOS). Evidence from other individualised or patient-specific outcome measures (see Dekker et al., 2005 and Donnelly and Carswell, 2002), particularly the evaluation of Bi-POMs and ERAIQ - which are similar to the Performance Profile whereby patients can choose words that best describe how they are feeling due to their injury - have both reported that these patient-specific P-BOMs (Bi-POMs and ERAIQ) were statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$) to Peak Force (PF) ($r= 0.72$ to 0.74, $p< 0.05$; $rs= 0.75$, $p< 0.05$, respectively) and with others[57]. This further illustrates that patient-specific outcome measures which are derived from selecting individual responses and scoring do indeed correlate with C-BOMs. To date, no comprehensive review or systematic evaluation of individualised outcomes has yet been published for ACL-related outcome assessment and this warrants much further investigation (Horn et al., 2012).



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[57] Other statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$) relationships were found between:

I. Bi-POMs negatively correlated with EMD ($r = -0.77$, $p< 0.05$ [depressed-elated]) and ATFD ($r = 0.72$ to 0.87, $p< 0.05$ [hostile-agreeable, tired-energetic]) at 8 weeks post-ACLR surgery.
II. ERAIQ associated with the discouraged and pain sub-scales both positively correlated with ATFD ($rs = -0.79$, $p< 0.01$; $rs = 0.78$, $p< 0.01$, respectively).

FIGURE 13 - Range scores of correlation coefficients reported illustrating four commonly-used ACL P-BOMs (IKDC, Lysholm, KOOS, and Cincinnati) evaluated with C-BOMs (group categories [p. 139]). **NOTE**: Range scores in **RED** for the Performance Profile.

3.7a - Strengths, Weaknesses and Future Recommendations

At the time of this systematic review, no other systematic reviews or meta-analyses were either published or in progress, therefore the presented study was the first attempt to systematically evaluate the relationship between a range of P-BOMs and C-BOMs concomitantly with an ACL-deficient population. Although the Systematic Review was confined to ACLD and ACLR patients, it could have included other knee pathologies to allow a wider understanding of concomitant relationships. The inclusion of other populations (i.e., OA) may have impacted the external validity of the results, and might have allowed a suitable number of sub-sets to be included within a subsequent meta-analysis. With all this in mind, future research would be needed to address the same research questions within larger scale research trials, or examine other knee pathologies to understand further the relationships between P-BOMs and C-BOMs. However, for the purpose of this study, the latter would have been impossible to achieve in the time-frame allowed for this PhD programme of research.

Within the systematic reviewing process, all studies had to be available in the English language as translation into English was not feasible within the time-frame of this review. Only two non-English studies were found, but these were not included in the Systematic Review for this reason. Although unlikely, these two studies could potentially have changed the outcome of this review, therefore future research should include all published research in any language, particularly as discussed above with other populations and RCTs.

The methodological quality assessment for this study was conducted using a modified version of the 'Cochrane Methods Group on Screening and Diagnostic Tests Methodology' (Devillé et al., 2002) in accordance with Gokeler et al. (2012), as was deemed appropriate to the type and design of the studies presented in this review. The mean of the methodological quality score of all studies was 9.3 ± 1.5 (Mean ± SD) [out of maximum score of 16]. All the studies had a low level of evidence as assessed against the Oxford Centre for Evidence-based Medicine Levels of Evidence. None of the reviewed studies scored higher than level 2 of evidence with a score of 1.24 ± 0.44 (Mean±SD. As reported by Gokeler et al. (2012), a combination of the CM assessment scale and the Oxford Centre of Evidence levels was necessary, since there is currently no specific checklist available to assess the methodological assessment with the design of the studies included in this review. In addition, the authors note that this modified scoring system is arbitrary, yet it was necessary to use this assessment scale to compare the included studies (Gokeler et al., 2012). It is important that the methodological quality assessment of these studies, conducted within the review, and the results obtained should be viewed with caution, and any extrapolation of these results should be considered with even greater caution. To confirm the exact relationship between P-BOMs and C-BOMs concomitantly, further research would be required and in this process the methodological design of new studies should consider their flaws which are reported (see below). Only with future studies reporting greater levels of methodological efficacy will greater confidence in their results be obtained.

Furthermore, many of the studies contained common weaknesses in their methodological design, as identified from the checklist, with only four studies assessing reliability. Equally, few studies provided an appropriate description of the patient's demographic details or provide sufficient information on how data was collected. For example, limited descriptive data was reported for the time from ACL injury to ACLR surgery to the evaluation time points of each study. Moreover, much of the correlational data was not reported. This all contributed to further complicating the ability to gain a true understanding of the relationships between P-BOMs and C-BOMs.

The presented Systematic Review only investigated the relationships among P-BOMs and C-BOMs concomitantly, therefore further research should investigate the inter-correlation of P-BOMs and C-BOMs separately. The IKDC has been investigated more rigorously than other P-BOMs which should include the Cincinnati, VAS (Pain), Oxford-12, WOMAC, KOOS, and Lysholm (Metsavaht, Leporace, Riberto, De-Mello Sposito, and Batista, 2010; Agel and Laprade, 2009). The current literature suggests that the majority of research has predominately assessed inter-correlations at short-term (1 year post-surgery) to long-time frames from 5 to 25 years post-surgery for ACL deficiency (Cartwright-Terry et al., 2014; Briggs et al., 2009), with fewer studies directly evaluating inter-correlation of P-BOMs within an ACL rehabilitation period (i.e., surgery to 6 months' post-ACLR surgery) (Van Meer et al., 2013; Cartwright-Terry et al., 2014). As this was not feasible within the time-frame of this thesis, potential future research would need to evaluate such inter-correlations (i.e., P-BOM and C-BOM outcomes evaluated in isolation) within systematic approaches evaluating the literature in a similar manner to the systematic review.

The examination of non-correlational studies (i.e., randomised controlled trials) would potentially provide other correlational information, however, the given the time needed to perform a wider Systematic Review of a large number of studies, together with a more time-intensive screening process of such details was not feasible within this study. As such, relationship data within RCTs is reported more sparsely and would require a considerable period of time to extract. Therefore, it would be interesting to examine more widely the relationship between P-BOMs and C-BOMs from other empirical research to further investigate these relationships, as well as to evaluate other clinical populations (i.e., OA, TKA), to establish accurate relationships amongst these outcome measures and differing groups of patients.

Within the reviewing process, it was difficult to comment upon the proportion of correlation coefficients that were statistically significant versus non-significant for the same outcome measures as reported in this review. Firstly, this study only addressed the significant correlation coefficients ($p< 0.05$), whereas it would be just as important to address the non-significant relationships to ascertain those which are frequently reported to be non-significant. Secondly, understanding the actual proportions of correlation coefficients which did not indicate statistical or clinical relevance could, potentially, allow a further understanding of the miss-match of P-BOMs and C-BOMs. It would be advisable that future research to continue in this way.

Finally, the outcome of this review cannot ascertain with certainty the relationship between P-BOMs and C-BOMs, as it was observed that a diverse number of P-BOMs/C-BOMs were found which were mostly non-comparable with no same P-BOM consistently being evaluated with the same C-BOMs. Therefore, the strength of relationships remains unknown and is relatively speculative, warranting further investigation. A subsidiary aim was to understand the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly during 24 weeks of ACL rehabilitation which could not be evaluated absolutely. The logical progression would therefore be to further evaluate a range of P-BOMs and C-BOMs within the different phases of rehabilitation (i.e., acute, intermediate, and late) as it was not possible to do this from the results of this systematic review.

It would be particularly important to incorporate a range of P-BOMs and C-BOMs measured simultaneously within a single clinical population, since many of the correlational studies only examined a small number of comparisons. Moreover, as found in this review, a select number of P-BOMs[58] and C-BOMs[59] were statistically significant and demonstrated potential clinical relevance and these outcomes may require further validation. For the C-BOMs, for example associated with dynamometry such as PT and TW, which were evaluated by knee flexors and knee extensors, it would be useful to evaluate relationships between muscle groups of the injured and non-injured limbs as this correlational information was not obtained and could not be commented upon.

Further, the Performance Profile (a P-BOM) was found to be consistently and, in most instances, highly correlated with several C-BOM methods of assessment which forms the novelty of this investigation into the Performance Profile in this thesis. Noteworthy, is that in considering the much larger correlation coefficient values reported from both performance profiling studies (Gleeson et al., 2008; Yates et al., 2016) in comparison to other commonly deployed ACL outcome measures (i.e., IKDC, KOOS, and Lysholm) versus several C-BOMs (Single-Leg Hop for distance and PF, EMD, and RFD, SMP-FE), and combined with the relatively low sample sizes for each profiling study, indicates that further investigation into the profiling methodology might provide

[58] **P-BOMs**: Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance profile.
[59] **C-BOMs**: Hop [6m-timed], Stairs Hopple (timed), ATFD, PF, PT, TW, and EMD.

interesting insights for its use within a clinical setting. A better understanding of these relationships would help establish if any strong relationships do exist amongst the candidate outcome measures, which could ultimately reduce the number of P-BOMs and C-BOMs required to assess patient outcomes post-ACLR surgery. This might also permit informed speculation over the number of outcome measures required within rehabilitation to correctly describe progression, and an understanding of the hierarchy of importance of the outcome measures would help properly describe changes in functional capacity.

3.8 - Conclusion

This Systematic Review was a first attempt to systematically evaluate the P-BOMs and C-BOMs concomitantly with an ACL-deficient population. A total of twenty-six P-BOMs and forty-six C-BOMs were found during the reviewing process, illustrating the diversity of outcome measures available to assess study outcomes. For this reason, the studies were mostly non-comparable with no same P-BOMs being consistently evaluated with the same C-BOMs. Approximately 9% of all relationships found (36/388) were both statistically significant ($p < 0.05$) and demonstrated potential clinical relevance ($r \geq 0.70$). Unfortunately, the outcome of this study does not support the single use of one P-BOM and/or C-BOMs at pre-surgery, or across the acute, intermediate, and late phases of rehabilitation, and up to 5 years post-injury or surgery as a means of accurately reflecting knee performance with ACL deficiency.

Therefore, at present, it remains unknown which outcome measures (P-BOM or C-BOM) are required to effectively deliver a truly ‘global’ assessment of a patient following ACL injury (Howe et al., 2012). The consistent lack of statistically significant and clinically relevant correlation between P-BOMs and C-BOMs highlights the challenges faced by clinicians and researchers. These include determining the minimum number of either P-BOMs or C-BOMs required to properly describe changes in functional or physical performance of patients during their rehabilitation, and importantly, the dilemma of whether P-BOMs or C-BOMs offer most validity.

Moreover, it would appear that both P-BOMs and C-BOMs could contribute to separate, but potentially important, aspects of functional capability that cannot be causally linked. Thus, proxy-use of P-BOMs as efficient substitutes for C-BOMs could not be recommended based on the thesis results. Clinicians should therefore be cautious about planning/progressing rehabilitation based on a single outcome measure, but must continue to deploy multiple P-BOMs and C-BOMs. Further research is required in this area.

However speculative, several P-BOMs (Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance Profile) were shown to be statistically significant ($p < 0.05$) and demonstrated potential clinical relevance ($r \geq 0.70$) to a few C-BOMs (Hop [6m-timed], Stairs Hopple (timed), ATFD, PF, PT, TW, and EMD) for both ACLD and ACLR individuals at intermittent time points. An interesting observation was that a patient-specific P-BOM, or individualised P-BOM, such as the Bi-BOM, ERAIQ and the Performance Profile, were found to be distinctly different to the remainder of the P-BOMs, also found to be significant/clinically relevant.

In summary, the findings of this Systematic Review **(Study 1)** have key implications for clinical practice which suggests that **(1 :)** with the absence of strong relationships which are infrequently linked among P-BOMs and C-BOMs, each outcome measure might be contributing to a separate, but potentially important aspect of function and recovery, but with no causal linkage; **(2 :)** the proxy-use of P-BOMs as efficient substitutes for C-BOMs cannot be envisaged based on the results of this study; **(3 :)** the lack of correlation among P-BOMs and C-BOMs could potentially lead to sub-optimal conditioning within rehabilitation therapy, with patient's perceived capabilities being mismatched to the objectively-derived measurements; **(4 :)** the mismatch between patient perceptions and actual function performance capabilities could in fact increase the risk of further injury if the patient chose to undertake activities for which they are unprepared; **(5 :)** clinical practice should continue to deploy numerous P-BOMs and C-BOMs to holistically evaluate patient outcomes; and **(6 :)** physiotherapists should avoid promoting a patient rehabilitative regime based on the development of aspects of performance focusing on a single outcome measure.

CHAPTER FOUR

GENERAL METHODS

4.1 - Methods

Four studies are contained within this thesis and are reported in Study 1 **(Chapter 3: Systematic review;** p. 113), Study 2 **(Chapter 5: Correlation investigation;** p. 202)[60], Study 3 **(Chapter 6: Reliability investigation;** p. 281), and Study 4 **(Chapter 7: Intervention RCT investigation**; p. 312**)**. All four studies share a similar experimental and assessment procedure and will be presented here.

4.2 - Patient Inclusion and Exclusion Criteria

All participants were selected from a cohort of patients presenting with arthroscopically verified unilateral complete ACL rupture following GP referral to the rehabilitation centre where the data for this thesis were obtained (Robert Jones and Agnes Hunt Orthopaedic and District NHS Trust Hospital. Physiotherapy Department, Oswestry). Following GP referral and meeting surgical criteria for ACL elective surgery, all patients fulfilling the inclusion and exclusion criteria were offered an opportunity to participate in either of the two clinically- and experimentally-controlled trials, Study 3 **(Chapter 6: Reliability investigation)** and Study 4 **(Chapter 7: Intervention RCT investigation)**, respectively, on a volunteer basis, by means of personal invitation. If participants decided not to undergo their rehabilitation at the rehabilitation centre, they would be unable to participate in Study 4 **(Chapter 7: Intervention RCT investigation)**, the randomised controlled trial, as all participants were required to attend all routine physiotherapy sessions.

No exclusions were made on the basis of gender or race, and patients over 16 years of age were deemed musculoskeletally and mentally mature enough to participate and were invited to take part all of the studies. Patients suffering from bilateral knee pathologies at the time of consent were excluded as the contralateral knee would not suffice in acting as a control limb[61]. Furthermore, patients with systemic conditions such as rheumatoid arthritis, chronic obstructive airways disease or cardiac pathology were excluded on the basis that their physiological responses to training would be compromised and their physical ability to take part in the rehabilitation programmes investigated in these studies would prove difficult and clinically inappropriate. All types of auto-graft sources and graft types were included; however, patients with synthetic ligaments, posterior cruciate ligament reconstruction or multiple ligament injuries would require an adaptation to the standard

[60] The raw data/scores of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) from Study 4 **(Chapter 7: Intervention RCT investigation)** evaluated at assessment occasions (pre-surgery, weeks 6, 12, 24 weeks post-ACLR surgery) were used to formulate this correlation study **(Study 2)**.

[61] When attempting to identify levels of ‘normal’ or improved function brought about by ACLR surgery and subsequent rehabilitation, the use of the contralateral asymptomatic leg as a baseline and control is prevalent and indeed, was used in this way, in Study 3 and Study 4.

rehabilitative physiotherapy protocols for rehabilitation following ACL reconstructive surgery and were therefore excluded (Legnani et al., 2010).

TABLE 14 - General eligibility criteria.

Inclusion criteria:	**Exclusion criteria:**
• Participants to have the capability to fully understand the implications of the research studies and volunteered to take part on the understanding that they may leave the studies at any time without giving a reason and without this affecting their treatment in any way. • Adults over 16 years of age to ensure musculoskeletal and mental maturity. • Listed for ACL reconstructive surgery following informed surgical consent. • Patients were under the care of one of four surgeons identified to perform the surgery. • Participants will have no other physical or mental impairment that would limit them. • Autologous graft tissue; either patella tendon or semitendinosus and gracilis from the ipsilateral leg. Participants must attend their physiotherapy sessions only within the investigation's rehabilitation/testing centre for the duration of the study following ACLR surgery[62]. • Participants will be able to attend all pre-arranged physiotherapy sessions following ACLR surgery[63]. • Participants will be able to attend all stipulated assessment sessions (at pre-surgery, week 6, week 12, and week 24 post-ACLR surgery)[64]. • All ethnic groups. • Male or Female.	• Patients with systemic pathologies. • Bilateral knee injuries at the time of consent. • Multiple ligament injuries to the knee. • Declined to participate in any of the studies.

[62] This inclusion criteria is for Study 4 **(Intervention RCT investigation)** only.
[63] This inclusion criteria is for Study 4 **(Intervention RCT investigation)** only.
[64] This inclusion criteria is for Study 4 **(Intervention RCT investigation)** only.

4.3 - Recruitment of participants and study selection

The initial recruitment of potential patients was conducted as a two-stage process. Firstly, each patient was approached by one of the four consultant orthopaedic surgeons involved in the research trials at each patient's preliminary consultation, following GP referral. A brief introduction to the two research studies (Study 3 **[Chapter 6: Reliability investigation]**; Study 4 **[Chapter 7: Intervention RCT investigation]**) was presented to patients individually. Each patient was allowed to discuss any surrounding issues regarding the study designs, the rehabilitation process, and their involvement with their surgeon. As the thesis author, I also attended each of the consultation appointments for verification of any other questions or concerns that arose.

Patients were given a Participant Information Sheet **(APPENDIX 10**; p. 573**)**, as well as access to a web page at the end of this first consultation for them to review at a later date. All patients could seek independent advice if required, via contact information on the participant information sheet. In addition, each patient was provided with contact details for a qualified physiotherapist (associated clinical research team), which would allow them to seek further information if required, at any time. At this initial consultation, informed consent was also obtained from each patient so they could be contacted at a later date by the author of this thesis to discuss their potential involvement in the any of the studies **(**see Consent Form, **APPENDIX 11**; p. 577**)**. If consent was not obtained, patients were not contacted. Each potential participant had at least one month to consider whether they wished to participate in any of the studies.

During a second consultation, generally conducted within four weeks prior to ACLR surgery, each patient was reminded of each study's design by the same consultant orthopaedic surgeon. In some instances, several patients did not have to attend a second consultation. In this case, patients who had previously provided informed consent at their first consultation were contacted by myself, as the author of this thesis, to confirm their involvement and, if required, to address or answer any remaining concerns or questions before inclusion in any of the studies.

Patients attending their second consultation were allowed to raise further concerns or questions regarding, and prior to, their involvement upon giving their informed consent to participate. Each participant was made fully aware, both verbally and in writing, of the implications of the presented studies. Each participant was reminded that they may leave any of the studies at any time without giving any reasons. A patient's decision to withdraw from any of the studies would not detract in any way from the quality of treatment they were to receive. Moreover, the relationship between the patient, the physiotherapist, the consultant orthopaedic surgeon, and anyone else involved in the rehabilitation process would not change.

4.4 - Participants and Study Allocation

Once acceptance of and compliance with the study protocols was obtained together with written consent to participate, all participants were invited to Study 3 **(Chapter 6: Reliability investigation)** which was conducted within two weeks prior to each patient's own ACLR surgery. Study 3 was conducted from August 2012 to April 2013 (8-month duration). Patients who had elected to continue with post-ACLR physiotherapy at the rehabilitation/testing centre (same hospital as surgery), were randomly allocated to the conditions of the experimental (PPM) and control (CON) rehabilitation group. All participant randomisation and allocation to the studies, and/or experimental and control groups were within published tables of a random sequence of numbers (for example, Winer, 1981). Study 4 **(Chapter 7: Intervention RCT investigation)** was conducted from January 2013 to August 2014 (18-month duration).

All studies met the ethical standards suggested by Harriss and Atkinson (2009), and all studies were approved by the Ethics Committee for Human Testing by Queen Margaret University, Edinburgh, UK, and by the Shropshire area NHS Ethics Committee (REC reference: 05/Q2601/36). Further, all studies had received scientific merit approval from the Research Committee of Robert Jones and Agnes Hunt Orthopaedic and District Hospital Foundation NHS Trust, UK. All of the information collected during the course of this research thesis was kept strictly confidential, and the rights of all participants were protected. Study and group allocations are schematically illustrated in **FIGURE 14** (p. 167).

4.5 - Experimental and Assessment Procedures

Within two weeks prior to all surgeries, all patients attended their first assessment/testing session (pre-surgery assessment). The following descriptive data (age etc.) and anthropometric measurements (height, body mass, etc.) were recorded: the height of each participant was measured by stadiometer which is a portable instrument composed of vertical measuring board and a horizontal headboard. The patients were asked to take their shoes off and stand against the vertical board with knees straight and heels touching each other, keeping their head in a normal anatomical position by looking forward in a straight line. The weight of each participant was measured in kilograms (kg) with shoes and outer clothing removed, using a weighing scale with a range suitable to the participants' sizes. The scales were at zero and their accuracy was checked regularly using standard weights.

The first assessment session included a familiarisation phase and was devised to obtain baseline pre-surgery measures, assessed by C-BOMs that included knee stability evaluated by knee arthrometry (see p. 190), knee strength evaluated by dynamometry (p. 194) and neuro-muscular performance outcomes (see p. 195-197), sensorimotor performance/capability (p. 191), and P-

BOMs [VAS (Pain) (p. 176), IKDC (p. 171), KOOS (p. 174), Lysholm (p. 177), and Performance Profile (p. 181)].

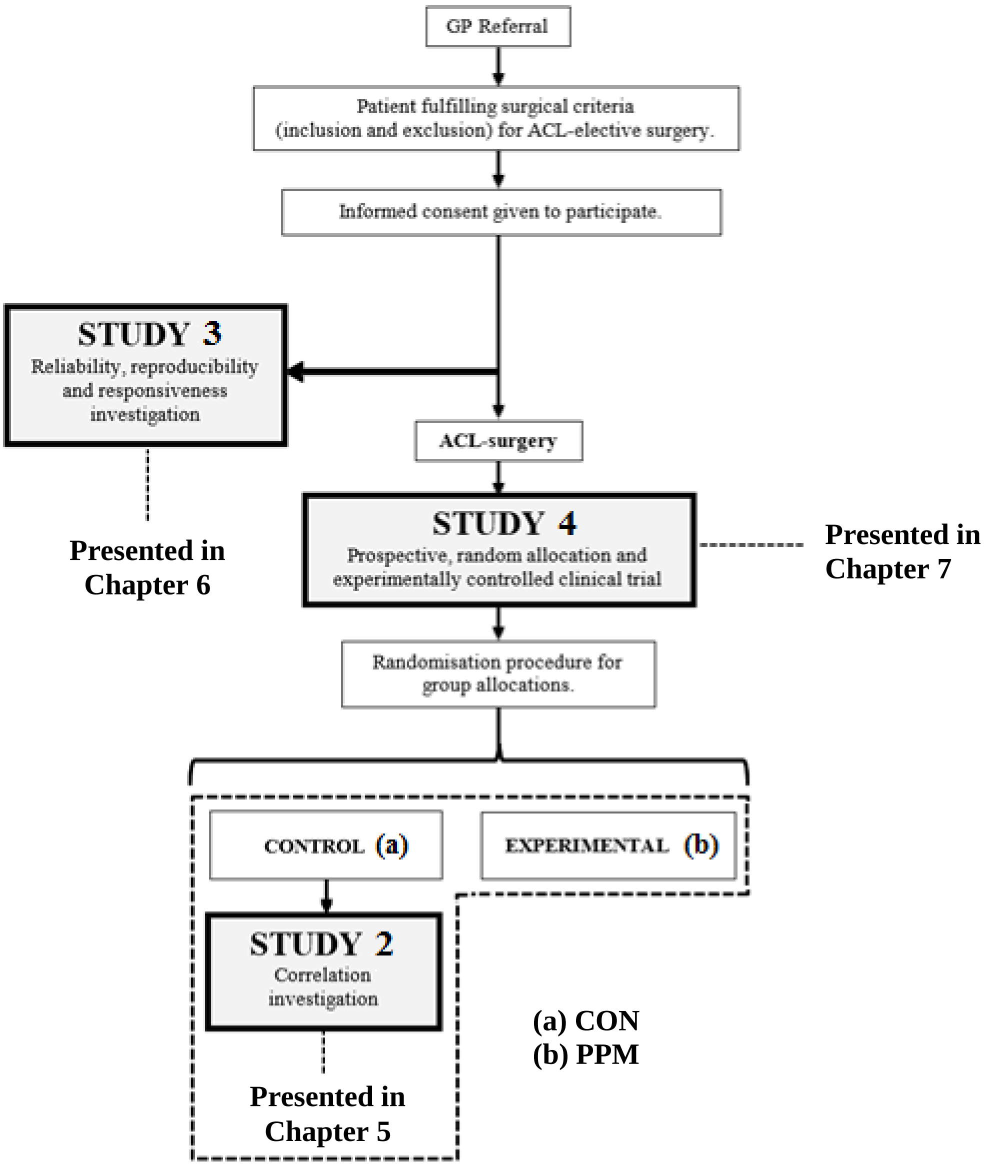


FIGURE 14 - Participant random allocations to studies and subsequent experimental (PPM) and control (CON) rehabilitation groups.

NOTE:

[1:] Study 1 (Systematic review) is excluded and presented in **Chapter 3** (see p. 113).

[2:] The raw data/scores of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) from Study 4 **(Chapter 7: Intervention RCT investigation)** evaluated at assessment occasions (pre-surgery, weeks 6, 12, 24 weeks post-ACLR surgery) were used to formulate this correlation study (Study 2). The Performance Profiling Management (PPM) and contemporary rehabilitation (CON) group conditions (see p. 329) were examined separately, to ascertain whether relationships among P-BOMs and C-BOMs differed between PPM and CON rehabilitation groups.

All patients participating in Study 4 **(Chapter 7: Intervention RCT investigation)** were required to attend subsequent assessment and testing occasions conducted at 6, 12, and 24 weeks post-ACLR surgery. Regardless of the study group allocations (PPM and CON), all participants were required to complete the standardised assessment/testing protocols outlined in **FIGURE 15**. The experimental design comprised of a longitudinal comparison of the leg undergoing ACLR surgery with a contralateral limb control during a 24-week period of physical rehabilitation. The assessments and the order of testing legs were undertaken in a random sequence determined from a computer-generated list of numbers before each assessment/testing occasion.

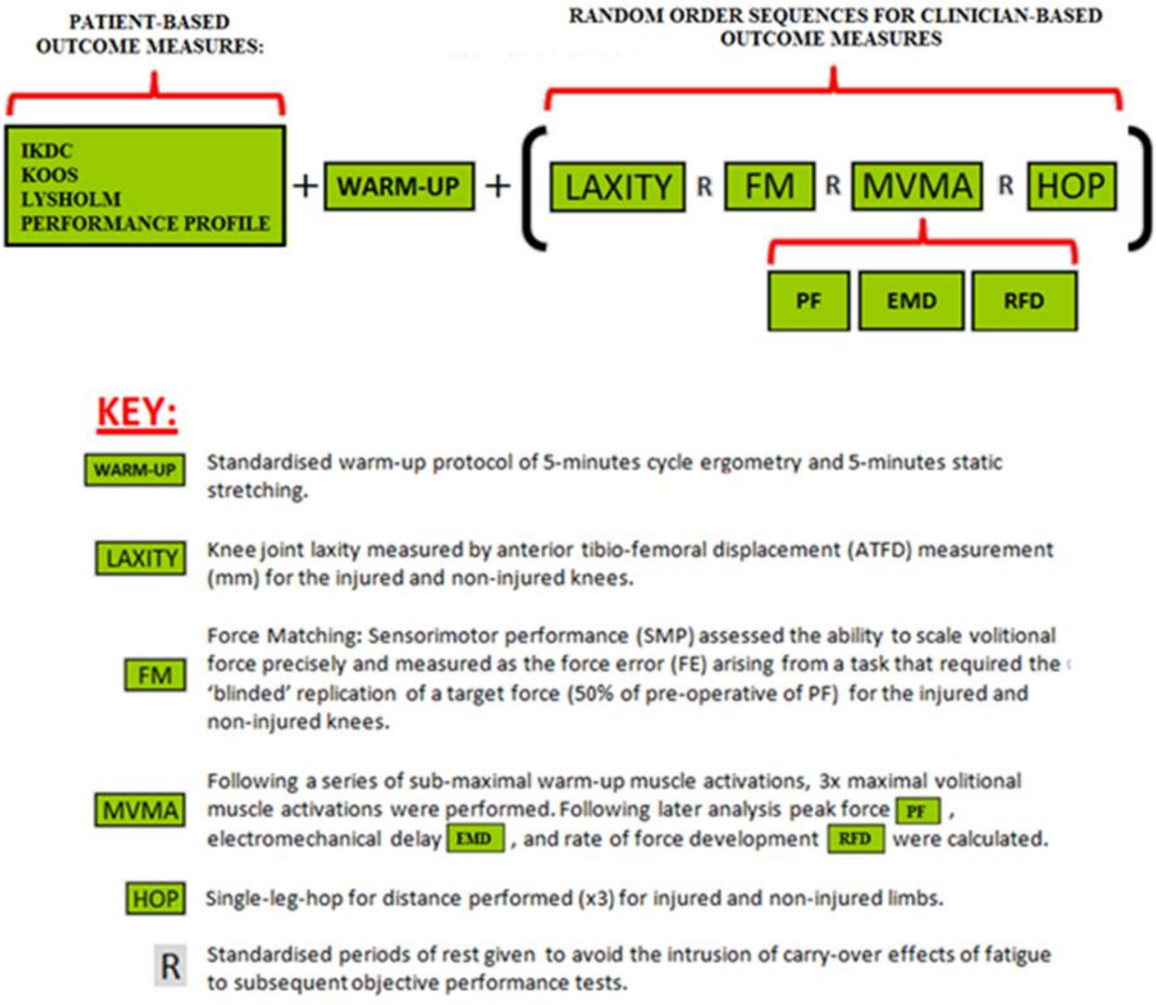


FIGURE 15 - Schematic of the assessment protocol associated with surgical reconstruction of the anterior cruciate ligament and subsequent post-operative physical rehabilitation with P-BOMs and C-BOMs (Source: Author's own diagram).

4.6 - Rehabilitation programme

All patients were treated by the same physiotherapist and followed a standardised and established program of rehabilitation used in current clinical practice (RJAH, 2007 **(APPENDIX 1**; p. 440**)**. The rehabilitation programme was divided into three phases: acute, intermediate, and late.

4.6.1 - Acute phase (0-6 weeks) rehabilitation

The first 6 weeks of standard rehabilitation exercises considered the gaining of the full range of motion, especially terminal extension/hyper-extension in the injured limb, gait re-education, static cycling, and the use of rowing and elliptical cross-trainer machines, step-ups, active and resisted exercises of the upper body, core stability and proprioceptive activities.

4.6.2 - Intermediate phase (6-12 weeks) rehabilitation

During the intermediate stage (6-12 weeks post-ACLR surgery), proprioceptive work was increased, resisted exercises (with the exception of throughout the range open-kinetic chain (OKC) extension) were introduced and the difficulty of other activities (i.e., , step-ups, one-legged dips) was increased; ‘early plyometric’ exercises were added in the form of jumps, leaps and hops in partial weight-bearing scenarios, using a set of parallel bars in-front of a mirror to correct any biomechanical errors and to familiarise the lower limb joints with synchronised work at speed.

4.6.3 - Late phase (12-24 weeks) rehabilitation

During the late phase of the rehabilitation (12-24 weeks post-ACLR surgery) there was an increased emphasis on dynamic neuromuscular training including plyometric and agility drills. Once an appropriate level of eccentric quadriceps control was established interval treadmill walk/jog was added, progressing direction, volume and pace systematically; full weight-bearing double leg jumps on the spot was progressed to travelling forwards, backwards, sideways, 180° rotations and jumping from a step, advancing to single leg work. From approximately week 16, predictable twisting/turning agility circuits were added under supervision, and from week 20 unpredictable sports-specific agility training on the sports field was included. This naturally progressed to contact sport training from 24 weeks and a graduated return to all sporting activity there-after.

4.7 - Determining Minimally Detectable Change (MDC) and Minimal Clinically Important Difference (MCID)

Jaeschke et al. (1989) coined the term Minimal Clinically Important Difference (MCID) in 1989, since while assessment tools (or outcome measures) can establish statistically significant post-intervention changes, the changes may not actually be either clinically relevant or significant to clinicians or patients (Cook 2008). MCID has come to be used to distinguish between what is considered clinically important and what is of no clinical importance (Collins et al., 2011), with Greco et al. (2010, p. 894) defining MCID as "the change score that serves as the optimal cut-off point for discriminating individuals who perceive themselves to be improved from those who do not". Simply put, MCID is the lowest threshold value for this decision (Jaeschke et al., 1989; Copay et al., 2007; Revicki et al., 2008).

At present, a number of different methods (approximately 9) are used to calculate an MCID value since there are a number of different factors that can influence this value. Some of these methods anchor purely on external criteria, while others involve the instrument used to measure internal values (Cook, 2008). Unfortunately, MCIDs can vary widely depending on the method used, and at present there is no standard method for their calculation, which has resulted in various methodological and interpretation problems. In addition, patient populations suffering different pathologies might have different MCIDs for the same outcome measure, therefore, since there is currently no consensus regarding the best method, calculating an MCID is a real challenge (Jaeschke et al., 1989; Copay et al., 2007; Revicki et al., 2008).

To further complicate matters, there are a number of measures that mimic MCIDs, most notably the MID (Minimally Important Difference), MCD (Minimal Clinical Difference), or the MCSD (Minimal Clinically Significant Difference)[65]. Although similar in wording, these terms are actually very different in meaning and typically involve change values beyond the variations of the instrument (Cook, 2008). Nevertheless, clinicians continue to use a variety of methods to obtain MCID values for an assessment tool to determine its confidence in detecting actual meaningful clinical change (Reid et al., 2007). Collins et al. (2011), for example, ascertained knee function MCID using P-BOMs including Lysholm, KOOS, and IKDC, concluding that the cut-off points distinguishing patients who believed they had improved from those who believed they had not, represented meaningful changes to the patient. Moreover, Roos and Lohmander (2003) suggest that an 8-10-point change in a KOOS score might represent a minimal perceptible clinical improvement following ACLR. Unfortunately, Irrgang (2012) disputes this, suggesting that there are varied approaches to determining MDC, and that the MCID associated with the KOOS outcome score, has yet to be identified. Indeed, in some instances the C-BOMs and the effectiveness of the intervention are used to determine meaningful changes for patients, with an MCID for knee laxity and knee flexion angle being reported to be 3mm and 3.5°, respectively (Di Stasi et al., 2012). Whereby a loss of more than 3.5° in the knee flexion angle (i.e., MCID) was shown to have adverse effects on P-BOMs and C-BOMs (Shelbourne and Gray, 2009).

[65] Consult Katz, Paillard, and Ekman (2015) for a comprehensive review of determining the clinical importance of treatment benefits of interventions for orthopedic conditions.

The use of such diverse methods poses methodological challenges when attempting to unify the results of the respective studies (Cook 2008). **TABLE 15** (p. 170) summarises the minimal detectable changes (MDC: a cut-off point which does not necessarily represent clinical importance) for a P-BOM and C-BOM (where possible). Moreover, p. 173, 176, and 178 presents the psychometric characteristics of P-BOMs (IKDC, KOOS, and Lysholm), respectively.

4.8 - Outcome measures

4.8.1 - Patient-based outcome measures

P-BOMs (VAS [Pain], IKDC, KOOS, and Lysholm) are commonly-deployed outcomes to assess patient perspective following ACL injury (Wang et al., 2010; Collins et al., 2011). More so, these P-BOMs are deployed at the rehabilitation and physiotherapy centre and have been used throughout this thesis (while being freely available to practitioners online). All P-BOMs will be reported separately. The psychometric measurement characteristics of these P-BOMs (IKDC, KOOS, and Lysholm) are presented in **APPENDIX 12** (p. 578), and will be referred to in the discussion chapter 8 of this thesis. Psychometric data pertaining to the reliability and responsiveness of VAS [Pain] (p. 180), IKDC (**TABLE 15**; p. 173**)**, KOOS (**TABLE 16**; p. 176**)**, and Lysholm (**TABLE 17**; p. 178**)** P-BOMs are presented for each of the P-BOMs.

4.8.1.1 - International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form

The International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form is a knee-specific outcome measure developed for adults (Iversen et al., 2010), its purpose is to detect improvement/deterioration by assessing the domains of symptoms, function and sports activities as reported from the patient's perspective (Irrgang et al., 2001). The IKDC was developed in 1987 in an attempt to provide a uniform system for evaluating the results of knee ligament injuries, and the Subjective Knee Form was subsequently added in the year 2000 (Irrgang et al., 2001). The lack of patient contribution to the selection and revision of items in the IKDC, however, means that several aspects of validity cannot necessarily be assumed (Collins et al., 2011).

The IKDC is a multi-page form that includes demographic, current health assessment and subjective knee evaluation sections. This form includes 18 subjective questions evaluating symptoms, capability to participate in sports activities, and functionality associated with the knee joint. In the symptoms section, for example, patients are asked to state the highest level at which they could use their knee without having one of the significant symptoms (for example: pain, swelling, partial giving-way, and complete giving-way) even if they do not actually perform those activities. The IKDC is evaluated by calculating the difference between the raw score and lowest possible score and then dividing this difference by the range of possible scores multiplied by 100.

A high score (maximum scores of 100) denotes greater levels of function and symptoms (Irrgang et al., 2001).

The overall IKDC has also been shown to demonstrate acceptable psychometric and measurement properties in terms of good internal consistency, test-retest reliability, content and structural validity, and responsiveness and interpretability (no floor and ceiling effects) within a range of injuries to the knee joint (**TABLE 15**; p. 173**)**, which has reported minimal burden to the patient and clinician/researcher calculating IKDC score, and has become a popular patient-based method of assessment (Hambly and Griva, 2010; Grevnerts et al., 2014).

The specific areas the IKDC addresses are (Collins et al., 2011):

1. Symptoms, including pain, swelling, locking, catching and instability.
2. Sports activities, ranging from strenuous activities like skiing and tennis to tasks of daily living such as rising from a chair and ascending or descending stairs.
3. Rating current function compared to ‘normal’.

The items are then scored using the equation:

$$\text{IKDC Score} = \left(\frac{\text{Sum of Items}}{\text{Maximum Possible Score}}\right) \text{X } 100$$

For example, if the patient completed the form in full and the sum of scores for the 18 items was 45, the IKDC score would be calculated as:

$$\text{IKDC Score} = \left(\frac{45}{87}\right) \text{X } 100$$

$$\text{IKDC Score} = 51.7$$

TABLE 15 - The psychometric measurement characteristics (ICC = intra-class correlation coefficient; MDC = minimal detectable change; SEM = standard error of measurement; ES = effect size; SRM = standardised response mean; and MCID = minimum clinically important difference) of the International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form edited and adapted from Collins et al., (2011)[66]. † Large variation in time between test and retest (up to 12 months.

PATIENT COHORT EVALUATED	INTERNAL CONSISTENCY (CRONBACH'S A)	TEST–RETEST (ICC)	MDC	SEM	ES	SRM	MCID
Knee injuries (ACL, meniscal, chondral) [n= 4]	.77 – .91	.90 – .95†	8.8 – 15.6†	3.2 – 5.6†	Meniscal repair/resection (12 m): 2.11 Various cartilage procedures: 0.76 (6 m); 1.06 (12 m)	Meniscal repair/resection (12 m): 1.5 Various cartilage procedures: 0.57 (6 m); 1.0 (12 m)	Chondral injuries: 6.3 (6 m); 16.7 (12 m)
Cohort of mixed knee pathologies [n=7]	.92 – .97	.87 – .99†	6.7	2.4 – 4.6†	Various surgical procedures (6–28 m): 1.13	Various surgical procedures: 4.4 (4–8 m); 0.94 (6–28 m)	6–28 m: 11.5 (sensitive); 20.5 (specific)

[66] [n =]: The number of studies found within each cohort, as identified by Collins et al. (2011).

4.8.1.2 - Knee Injury and Osteoarthritis Outcome Score (KOOS)

The Knee Injury and Osteoarthritis Outcome Score (KOOS) is a site-specific P-BOM developed and validated to evaluate short-term and long-term symptoms and function in patients with a variety of knee injuries/pathologies (total knee replacement, meniscectomy, and ACLR) who are at risk of developing OA (ACL, meniscus, or chondral injury) (Van Meer et al., 2013).

The KOOS consists of 42 items across five sub-scales: [(1) pain frequency and severity during functional activities; (2) symptoms (stiffness and catching); (3) difficulty experienced in ADL; (4) sport and recreational activities; and (5) knee-related QOL] which are answered using a 5-point Likert scale. Each sub-scale (or component score) is calculated separately and converted to a 0-100 score, where 0 indicates extreme symptoms and 100 indicates no symptoms. In contrast to the IKDC outcome measure (as above), the IKDC is reported with a total (aggregate) score, as opposed to a sub-scale (or component) score calculated with the KOOS; as yet a total score has not been validated and is not recommended (Roos and Lohmander, 2003). The use of sub-scale scores has been reported to potentially enhance the clinical interpretation since different interventions like exercise therapy as opposed to pharmacology can have a greater impact on the different sub-scales, since exercise therapy interventions can affect ADL[67] and sport/recreation (sub-scale) more than pain and symptoms (Collins et al., 2011).

The KOOS has undergone a substantial amount of psychometric testing within the intended population/conditions (i.e., ACL) and has been found to have satisfactory levels of reliability, validity and responsiveness (Roos et al., 1998a; Roos et al., 1998b), with minimal burden to the patient and clinician/researcher calculating KOOS scores. It is also a popular patient-based method of assessment (Grevnerts et al., 2014).

The KOOS has demonstrated suitable psychometric properties/criteria for research, in particular demonstrating adequate reliability for use in groups, and validity with patients with knee injuries and knee osteoarthritis (**TABLE 16**; p. 176**)**. Moreover, the development of the KOOS P-BOM has been involved within the derivation of items (Garratt et al., 2004) as opposed to the IKDC which has been developed from the perspective of the patient (Hambly et al., 2010; Van Meer et al., 2013).

[67] Activity of Daily Living (ADL).

KOOS component scores:

1. Symptoms (7 items), including swelling, catching, grinding, range of movement and stiffness, etc.
1. Pain (9 items), including frequency and severity when performing tasks like walking, sitting and twisting, etc.
2. Functions of daily living (17 items), including stairs, dressing, and bathing, etc.
3. Functions of sports and recreation (5 items), including running, kneeling, jumping and squatting, etc.
4. Quality of life (4 items), including lifestyle modification and confidence, etc.

To calculate the KOOS score for pain, for example, the following equation was applied:

$$\text{KOOS Pain} = \left(\frac{\text{Mean Score of Pain items x 100}}{4} \right) - 100$$

The other domains (i.e., symptoms, function, sport/recreation, and QoL) were calculated in the same manner. The individual mean scores for each separate domain were all divided by 4 as this was the maximum score for each item. From this calculation, a patient scoring 0 would be considered as experiencing extreme knee problems, and a patient scoring 100 would be considered to have no knee problems at all. In addition, if a patient inadvertently placed a mark outside an assigned item score box, the closest box was chosen, and if two boxes were ticked the most severe was reported as per the KOOS instructions. With respect to missing data, the mean score of each independent domain can still be calculated unless 50% or more of the items within a domain is missing. If this occurred, the score for that domain would have been classed as invalid. However, no missing data was identified for the patients who completed study.

TABLE 16 - The psychometric measurement characteristics (ICC = intra-class correlation coefficient; MDC = minimal detectable change; SEM = standard error of measurement; ES = effect size; SRM = standardized response mean; and MCID = minimum clinically important difference) of the Knee Injury and Osteoarthritis Outcome Score (KOOS) edited and adapted from Collin et al., (2011)[68]. † Large variation in time between test and retest (up to 12 months).

PATIENT COHORT EVALUATED	INTERNAL CONSISTENCY (CRONBACH'S A)	TEST–RETEST (ICC)	MDC	SEM	ES	SRM
Knee injuries (n=5)	Pain: .84 – .91 Symptoms: .25 –.75 ADL: .94 – .96 Sport/rec: .85 – .89 QOL: .64 – .90	Pain: .85 – .93 Symptoms: .83 – .95 ADL: .75 – .91 Sport/rec: .61 – .89 QOL: .83 – .95	Pain: 6 – 6.1 Symptoms: 5 – 8.5 ADL: 7 – 8 Sport/rec: 5.8 – 12 QOL: 7 – 7.2	Pain: 2.2 Symptoms: 3.1 ADL: 2.9 Sport/rec: 2.1 QOL: 2.6	Partial meniscectomy (3 m): 1.11 (pain); 0.93 (symp.); 0.67 (ADL); 0.9 (sport/rec), 1.15 (QOL). **ACLR** (6 m): 0.84 (pain); 0.87 (symp.); 0.94 (ADL), 1.16 (sport/rec); 1.65 (QOL). ACI, MF (3 y): 0.82 (pain); 0.72 (symp.); 0.7 (ADL), 0.98 (sport/rec); 1.32 (QOL).	ACI, MF (3 y): 0.71 (pain); 0.61 (symp.); 0.75 (ADL); 0.87 (sport/rec); 0.76 (QOL). - -
Knee OA (n=5)	Pain: .65 – .94 Symptoms: .56 – .83 ADL: .78 – .97 Sport/rec: .84 – .98 QOL: .71 – .85	Pain: .8 – .97 Symptoms: .74 – .94 ADL: .84 – .94 Sport/rec: .65 – .92 QOL: .6 – .91	Pain: 13.4 Symptoms: 15.5 ADL: 15.4 Sport/rec: 19.6 QOL: 21.1	Pain: 7.2 – 10.1 Symptoms: 7.2 – 9 ADL: 5.2 – 11.7 Sport/rec: 9 – 24.6 QOL: 7.4 – 10.8	PT (4 w): 1.08 (pain); 0.97 (symp.); 1.07 (ADL); 0.79 (sport/rec); 0.78 (QOL). TKR (3 m): 2.59 (pain); 1.63 (symp.); 2.52 (ADL); 1.31 (sport/rec); 2.8 (QOL). TKR (6 m): 2.28 (pain); 1.24 (symp.); 2.25 (ADL); 1.18 (sport/rec); 2.86 (QOL). TKR (12 m): 2.55 (pain); 1.59 (symp.); 2.56 (ADL); 1.08 (sport/rec); 3.54 (QOL).	PT (4 w): 1.28 (pain); 1.02 (symp.); 1.37 (ADL); 0.83 (sport/rec); 0.87 (QOL). TKR (3 m): 1.85 (pain); 1.45 (symp.); 1.8 (ADL); 0.89 (sport/rec); 1.93 (QOL). TKR (6 m): 1.67 (pain); 0.99 (symp.); 1.7 (ADL); 0.81 (sport/rec); 1.6 (QOL). TKR (12 m): 2.12 (pain); 1.25 (symp.); 1.9 (ADL); 0.88 (sport/rec); 1.99 (QOL).

[68] [n =]: The number of studies found within each cohort, as identified by Collins et al. (2011).

4.8.1.3 - Lysholm Knee Score

The Lysholm was initially designed in 1982 for clinician administration and was primarily deployed to assess ligament injuries of the knee, principally knee instability from the perspective of the clinician (Lysholm and Gillquist, 1982; Tegner and Lysholm, 1985). However, since development of the Lysholm is surgeon-derived, content validity from the patient's perspective cannot be assumed. The Lysholm has since also been validated as a P-BOM to evaluate knee ligament injury and anteromedial, anterolateral, combined anteromedial/anterolateral, posterolateral rotatory, or straight posterior instability (Collins et al., 2011).

The Lysholm is an 8-item P-BOM that is scored on an increasing arbitrary scale from 0-100 with individual items being scored differently: (1) limp [0, 3, 5]; (2) support [0, 2, 5]; (3) locking [0, 2, 6, 10, 15]; (4) instability [0, 5, 10, 15, 20, 25]; (5) pain [0, 5, 10, 15, 20, 25]; (6) swelling [0, 2, 6, 10]; (7) stair climbing [0, 2, 6, 10]; and (8) squatting [0, 2,4, 5]. The total score is the sum of each response to the 8 items with a maximum possible score of 100, where 100 represents no symptoms or disability. Lysholm scores are categorised as: excellent (95-100), good (84-94), fair (65-83) and poor (≤64).

The Lysholm has been a popular P-BOM for a variety of knee conditions (Briggs et al., 2009; Wang et al., 2010) and has been validated by being a frequent and significant correlation between the Lysholm and C-BOMs, from the presented Systematic Review **(**see **TABLE 17**; p. 178**)**. Moreover, multiple studies have reported high convergent construct validity with significant correlations between HSS, Cincinnati, IKDC, Fulkerson and Kujala, WOMAC, Short Form 12, and Short Form 36 forms (Collins et al., 2011). The current literature suggests that the Lysholm has some instances of inadequate internal consistency in patients with a variety of knee conditions. Test-retest reliability is adequate for use in groups with knee injuries, but is less than adequate for groups with mixed knee pathologies. Minimal detectable change has been reported as ranging between 8.9 and 10.1 for knee injuries, while the standard error of the measure is reported to range from 3.2 to 3.6 for knee injuries and from 9.7 to 12.5 for mixed knee pathologies. Lastly, MCID and patient-acceptable symptom state (PASS) have not been calculated in any patient population (Collins et al., 2011).

Overall, the Lysholm Knee Score is reported to be reliable and valid having acceptable psychometric parameters of test-retest reliability, floor and ceiling effects, criterion validity, internal consistency (Paxton et al. 2003), construct validity, and responsiveness to change (Briggs et al. 2009).

TABLE 17 - The psychometric measurement characteristics (ICC = intra-class correlation coefficient; MDC = minimal detectable change; SEM = standard error of measurement; ES = effect size; SRM = standardized response mean; and MCID = minimum clinically important difference) of the Lysholm Knee Score (Lysholm) edited and adapted from Collin et al., (2011)[69]. † Large variation in time between test and retest (up to 12 months).

PATIENT COHORT EVALUATED	INTERNAL CONSISTENCY (CRONBACH'S A)	TEST–RETEST (ICC)	MDC	SEM	ES	SRM
Knee injuries (ACL, meniscal, chondral; patellar dislocation) (n=5)	.65 – .73	.88 – .97	8.9 – 10.1	3.2 – 3.6	**ACLR**: 1.0 (6–9 m); 1.1 (1–2 y)	**ACLR**: 0.93 (6 m); 1.1 (9 m); 1.2 (1 y); 0.93 (2 y)
					Meniscal repair (1 y): 1.2	Meniscal repair (1 y): .97 – 1.13
					MF (1–6 y): 1.2	MF (1–6 y): 1.1
Mixed knee pathologies (n=5)	.60 – .73	.68 – .95	–	9.7 – 12.5†	PT (1 m): 0.9	Variety of nonsurgical and surgical interventions (3 m): 0.9

[69] [n =]: The number of studies found within each cohort, as identified by Collins et al. (2011).

4.8.1.4 - Visual Analogue Scale (VAS) for pain

Analogue scales can be either numerical rating scales (NRS), or visual analogue scales (VAS) or a combination of the two (see **FIGURE 16**). NRS/VAS allow the patient to quantify the degree of pain they perceive at a particular time (Shaw et al., 2005). This is indicated by a single number, or by using a decimal point system (i.e., 3.0, 4.6, 5.7) (Clark, 2001), with written descriptors at the extremities of the horizontal line to provide reference points for the patient to consider (0 = no pain; 10 = extreme pain) (Kersten, 2012).

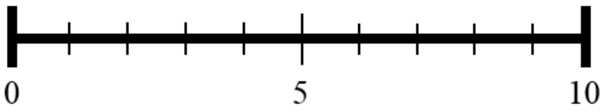


FIGURE 16 - Visual analogue scale (VAS) for measurement of pain
(Source: Author's own diagram)

The VAS line was 100 mm in length. Studies have shown that this line length (ranging from 100-150 mm) is the easiest for patients to use and results in the smallest measurement error. Overall, the VAS is a sensitive, reliable, and easy P-BOM for the evaluation of pain (Murray et al., 2013) **(TABLE 18)**.

TABLE 18 - The psychometric measurement characteristics (ICC = intra-class correlation coefficient; MDC = minimal detectable change; and MCIC = Minimally Clinically Important Change) of the Visual Analogue Scale (VAS) for Pain edited and adapted from Kamper et al. (2009).

Psychometric property evaluated	**Result**
Test-retest reliability:	ICC 0.90, 11-point.
Responsiveness/Sensitivity to change:	Standardized response mean 0.2 - 1.7, 7- and 15-point.
	Standardized response mean 0.5-2.7, 7-point.
Face validity:	Pearson's r = 0.72-0.90 with patient-rated importance of change, 15-point.
	ICC 0.74 between clinician and VAS, 15-point.
	Spearman correlation 0.87 between clinician and patient-rated change, 7-point.
Construct validity:	Significant correlation with change on Roland Morris, Oswestry, Pain rating scale, asthma quality of life, hop test, various scales.
Clinical relevance:	Spearman 0.56 - 0.7 with patient satisfaction, 7-point.
MDC:	0.45 points on 11-point.
MCIC:	2 points on 11-point.
Meaningful improvement[70]:	≥ 5/≤ −5 on 15-point scale is meaningful improvement/deterioration.
	≥ 6 on 7-point scale is meaningful improvement.

[70] Arbitrary designations of meaningful improvement.

4.8.1.5 - Performance Profile

In accordance with the original protocols and procedures described by Butler and Hardy (1992), an individualised Performance Profile was implemented in three stages (see below) during an individual consultation. Butler and Hardy's (1992) traditional performance profiling procedure has since become a template from which a variety of alternative procedures have been adapted (Weston, 2005; Weston et al., 2008; Weston et al., 2013), with procedural variations being applied to suit the clinical nature of the studies within this thesis (Gleeson et al., 2008). The purpose of this section is to briefly describe how the profiling procedures used by patients to obtain their own Performance Profiles are conducted for this thesis. However, each chapter using the Performance Profile will use a different methodology and procedures; these additional profiling procedures will therefore be described in more detail in each associated methodological section linked to that study.

4.8.1.5a - Introduction and Elicitation

Prior to eliciting an individualised Performance Profile for any of the studies within this thesis, and as suggested by Weston (2008), each participant was introduced to the concept of performance profiling at least one week before the first initial assessment phase was to be conducted. In most instances, participants had four weeks, and this was to allow sufficient time for them to review and generate a list of potential qualities or attributes he or she felt were important to achieving full recovery following ACL injury. All participants were asked to consider the following question and to list as many potential answers to it as possible. The outcome of this eliciting phase would be to discuss patients perceived physical needs with the research team and associated physiotherapist. In the first attempt to assess each participant's perceived needs, each participant was asked to consider the following question, "What, in your opinion are the 'elements' of your knee in 'need' of physical rehabilitation or the 'elements' to be improved upon to obtain full recovery?" **(APPENDIX 9**; p. 572**)**.

The first stage of Butler and Hardy's (1992) Performance Profile referred to above was to examine how each patient was currently feeling about his or her current state. As suggested, each participant had been previously introduced to the Performance Profiling procedures and allowed to list a number of self-perceived needs (Weston, 2008). Following this preliminary discussion regarding the implications of performance profiling, the Performance Profiling procedure was re-introduced to each patient within a two-week period prior to all patients' surgery. As Ravenette (1977) suggested, because an individual may operate at a low level of consciousness, using the Performance Profile may allow patients to improve his or her own self-awareness (Butler et al., 1993); thus the rehabilitation team would then have an understanding of how the patient construes his or her recovery from injury and preparation for ACLR surgery.

Within the second stage of Butler and Hardy's (1992) Performance Profile, during an individual consultation participants were asked again to consider the question, "What, in your opinion are the 'elements' of your knee in 'need' of physical rehabilitation or the 'elements' to be improved upon to obtain full recovery?". Each participant was given as much time as needed to evaluate this question and complete a list elements or qualities (later referred to as 'constructs') answering this question. Participants were not restricted in the number of 'elements' or 'qualities' they could describe to explain his or her own self-perceived physical needs. However, for the purposes of this study, only items (constructs) describing physical needs were eligible for inclusion in their Performance Profile. It was also important to stress that there were no right or wrong answers, and that being honest about his or her perceived physical needs would help understand how each patient was feeling. In some instances, providing a patient with completed Performance Profiles reinforced the basic profiling procedure, and would emphasise what each patient would gain from this assessment, whilst providing them with an illustrative example of the end product.

If participants were unable to identify items (constructs), the research team asked questions to prompt them to describe suitable elements/qualities, since it has been suggested that such prompting can help bring personal 'elements/qualities' into consciousness (Butler and Hardy, 1992). In most circumstances, little prompting was required. However, for some participants it was necessary to illustrate some examples using previous Performance Profiles. Bannister and Fransella (1986) point out that it is important for Performance Profiles to retain the wording and terminology used by the patients in the recorded elements/qualities. Therefore, if a participant selected an element/quality listed from an example Performance Profile, the participant had the opportunity to revise this element/quality using their own terminology and meaning. The lists that were generated previously, at least four weeks before surgery, and those from this consultation were combined and discussed with the physiotherapist.

Following this discussion, the Performance Profile chart was completed by mapping each participant's perceived needs onto the perimeters of a Performance Profile chart **(**see **FIGURE 3**; p. 56**)**, and a blank Performance Profile collection sheet **(APPENDIX 9**; p. 572**)** . All the generated perceived physical needs were retained on all Performance Profile charts throughout the period of each patient's rehabilitation. All elements/qualities generated by each participant were discussed and clarified with the research team/physiotherapist to ensure their meaning was fully understood. A variety of personalised elements/qualities perceived as important to achieving full recovery were expressed, including physical descriptions and variations of the following elements: "pain," "stability," "support," "strength", "range of motion", "giving way", "change direction", endurance", "swelling", "stiffness", "confidence", "clicking", "grinding", "bruising," "numbness," "balance," and "coordination."

4.8.1.5b - Self-assessment

Once an inventory of 'elements/qualities' had been produced, participants were required to perform a self-assessment on their 'injured' limb for each of the identified perceived physical needs. Participants were asked: "How are you feeling at the present time on each of the 'elements' you have listed?" Participants used the response scale to answer this question, which ranged from [0] 'my knee feels far from recovered' to [10] 'my knee feels fully recovered'. The same self-assessment procedure was conducted for the 'non-injured' contralateral limb. Participants recorded their responses by shading the area which corresponded to the response scale, or simply wrote their response on the Performance Profile chart.

It was important that each participant completed his or own self-assessment of physical needs as they felt at the time of completion. Doyle and Parfitt (1996) suggested as a future recommendation, that using values correct to one decimal (i.e., a 100-point scale) as opposed to the 10-point scale may allow participants to respond in a more accurate manner. Therefore, participants were allowed to use a decimal point system in their responses (if required) to further discriminate between individual responses, for example, 4.5, 5.7.

Weston and colleagues (2013) reported that in the previous literature, other rating scales had been incorporated within numerous performance profiling self-assessment procedures. For example, Butler and Hardy (1989) utilised a one-to-seven scale, later revising it to a one-to-ten scale rating system (Butler and Hardy, 1992). It has also been highlighted that the key issue when implementing the rating of an individual's Performance Profile is that the scale used should be meaningful to the individual, whereby the athlete (or the patient in this case) has a good understanding of what constitutes a rating of one and what constitutes a rating of ten, and that the rating scales used are clear and specific (Weston et al., 2013). For statistical reasons (i.e., reducing clamping effect), a zero to ten rating system was adopted for all Performance Profile rating scales within this thesis.

Whilst the majority of Butler and Hardy's (1992) Performance Profiling research has adopted the procedure above, certain variations have been employed (Weston et al., 2013). Each participant was required to determine the relative importance of each element/quality, as with previous research (Weston et al., 2011), by asking each athlete to rank their profile items by order of importance for an elite performer in their sport (Butler and Hardy, 1992). However, for this thesis, the relative importance ratings of each construct were obtained by asking the patient to consider the question, "How important are each of the 'elements' you have listed?" Participants used a response scale which ranged from, 'of crucial importance' to 'not important at all'. For example, if a participant elicited a Performance Profile chart with twenty elements/qualities, they would rate them in order of importance from one to twenty. However, if a participant elicited only twelve elements or qualities, this patient would only be able to rank their importance from one to twelve. The patient's relative importance ratings for each element or quality were recorded around the perimeter of the Performance Profile for the injured limb only **(FIGURE 17**; p. 185**)**.

Interestingly, Gucciardi and Gordon (2009a) suggested that this method of identifying importance ratings would help understand the hierarchical ordering of importance that each athlete attached to their profile attributes and thus tap into the organizational structure of the athlete's interpretation system (Weston et al., 2013). In addition, and as originally proposed by Jones (1993), this method would enable the coach to categorise which qualities required attention to optimise performance. Within an intervention programme guided by an athlete's perceived needs, with periodic assessments using the Performance Profile, athletes were instructed to identify three areas that required greatest improvement, which were then used as discussion points so that athletes and their coaches could agree on possible actions to improve these areas (Weston et al., 2011b). This procedure was therefore used by the patient and physiotherapist to encourage and agree upon treatment strategies to overcome the patient's areas of perceived physical needs. However, for the purpose of Study 4 **(Chapter 7: Intervention RCT investigation)**, each perceived physical need identified as important was recorded by each patient. The five most important importance ratings (i.e., items rated 1 to 5) were then used by the physiotherapist to discuss with the patient how best to proceed to achieve improvements based on their perceived physical needs.

4.8.1.5c - Timing data

Pilot testing of the Performance Profile reported that familiarisation with the profiling procedure in terms of understanding the concepts and constructing suitable lists of perceived physical needs was assumed to be the most time-consuming constraint. To quantify this, the time taken to introduce the outlined Performance Profiling procedures, and the time taken to generate a final list of perceived needs to elicit an individualised Performance Profile were recorded. In addition, within the self-assessment stages, whereby each participant was required to report a response measure for each perceived physical need constructed in each participant Performance Profile and then indicate the importance of each perceived need, the time taken to complete each of these self-assessments was recorded by the patient on each Performance Profiling chart.

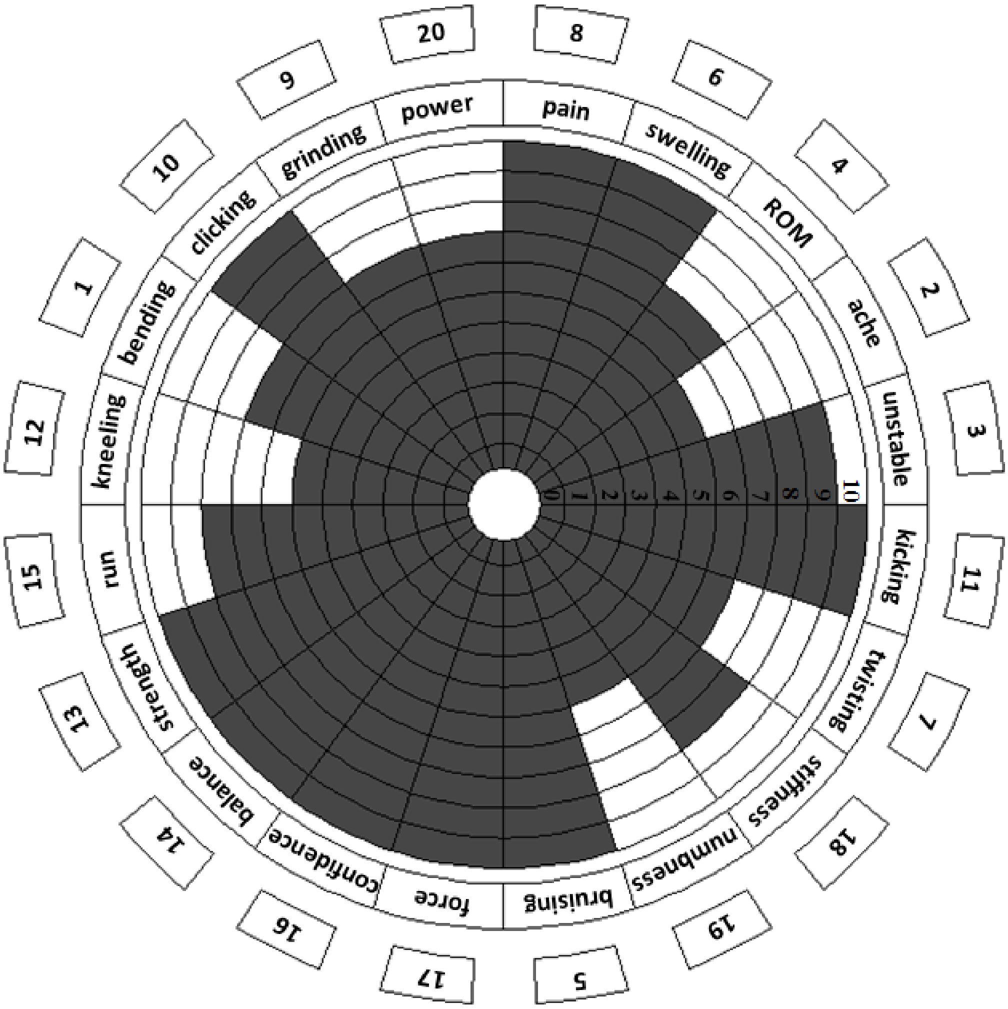


FIGURE 17 - Completed Performance Profile with the elements/qualities the patient perceives to be in need of rehabilitation and improvement displayed around the perimeter of the profile for the injured limb. **<u>NOTE</u>:** Hierarchical importance ratings of each element/quality which each patient felt needed to be improved upon first to obtain full recovery" (Response scale ranging from [1] 'of crucial importance' to [20] 'not important at all') (Source: Author's own diagram).

4.8.1.6 - Seven-day physical activity recall (7D-PAR)

It is important to quantify each participant's own exercise and rehabilitation conducted away from the rehabilitation testing/centre both at home and in leisure-based settings using the 7-Day Physical Activity Recall (7D-PAR). The 7D-PAR was assessed at four points in time (pre-surgery, week 6, 12 and 24) throughout the experimental period by each participant on discussing any home-based (and leisure-based) physical rehabilitation undertaken by the patient in that previous week, via memory recall.

In addition, each participant was instructed to complete the 7D-PAR on a daily basis away from the rehabilitation testing/centre to record any structured home-based (and leisure-based) physical rehabilitation, and to record the days when no physical activity was performed. The entries were therefore not based on memory recall. All physical activity (i.e., strength, cardiovascular and flexibility) was recorded by reporting the number of minutes spend performing each strength, cardiovascular and flexibility component together with the intensity (Blair, 1985). The 7D-PAR outcome measure is reported to a good general-purpose measure of physical activity (Blair, 1985; Montoye et al., 1996) with good psychometric properties of reliability and, in part, validity (Soundy, Taylor, Faulkner, and Rowlands, 2007).

Using the 7D-PAR allowed the researcher of this thesis to estimate the amount of home-based (and leisure-based) physical rehabilitation conducted within each of the four assessment occasions in accordance with the 7D-PAR guidelines and protocols. Although patient outcomes (measures of self-report) on their ability to carry out physical activities can be a useful insight, the literature often suggests that measures of self-report tend to overestimate or underestimate true physical activity, energy expenditure, and rates of inactivity. Moreover, methods of self-report often have issues with memory recall and response bias (i.e., social desirability, inaccurate memory) and can at times prove unable to capture the true level of physical activity performed (Prince et al., 2008).

The completed 7D-PARs made it possible to establish a more accurate evaluation of patients' physical activity/rehabilitation conducted away from the rehabilitation testing/centre. It is noteworthy, however, that being a clinician-based outcome measure, the 7D-PAR should not technically be completed in this manner, yet it proved a suitable medium for establishing home-based (and leisure-based) physical rehabilitation without using memory recall for the purposes of this thesis.

4.8.1.6a - Calculations of Metabolic Equivalents (METs) from 7D-PAR

The number of hours spent performing different activities reported in the 7D-PAR were calculated using the following guidelines (Sallis et al. 1993). Time spent in sleep (1 MET), light (1.5 METs), moderate (4 METs), hard (6 METs), and very hard (10 METs) activities over the past 7 days were multiplied by their respective MET values and then summed (Sallis et al. 1993).

An estimate of total kilocalories of energy expenditure per day was calculated, as in the following example.

Example (adapted from Sallis et al. 1993)

Data from the 7D-PAR:

Sleep: 60.0 h X I MET = 60 kcal/kg

Light: 99.5 h X 1.5 METs = 149 kcal/kg

Moderate: 3.5 h X 4 METs = 14 kcal/kg

Hard: 2.5 h X 6 METs = 15 kcal/kg

Very Hard: 2.5 h X 10 METs = 25 kcal/kg

Total weekly energy expenditure = 263 kcal/kg/wk

Total daily energy expenditure = 263 kcal/kg/wk ÷7 d/wk = 37.8 kcal/kg/d

For a 70-kg individual: 37.8 kcal/kg/d ×70 kg = 2646 kcal/d.

4.8.2 - Clinician-Based Outcome Measures

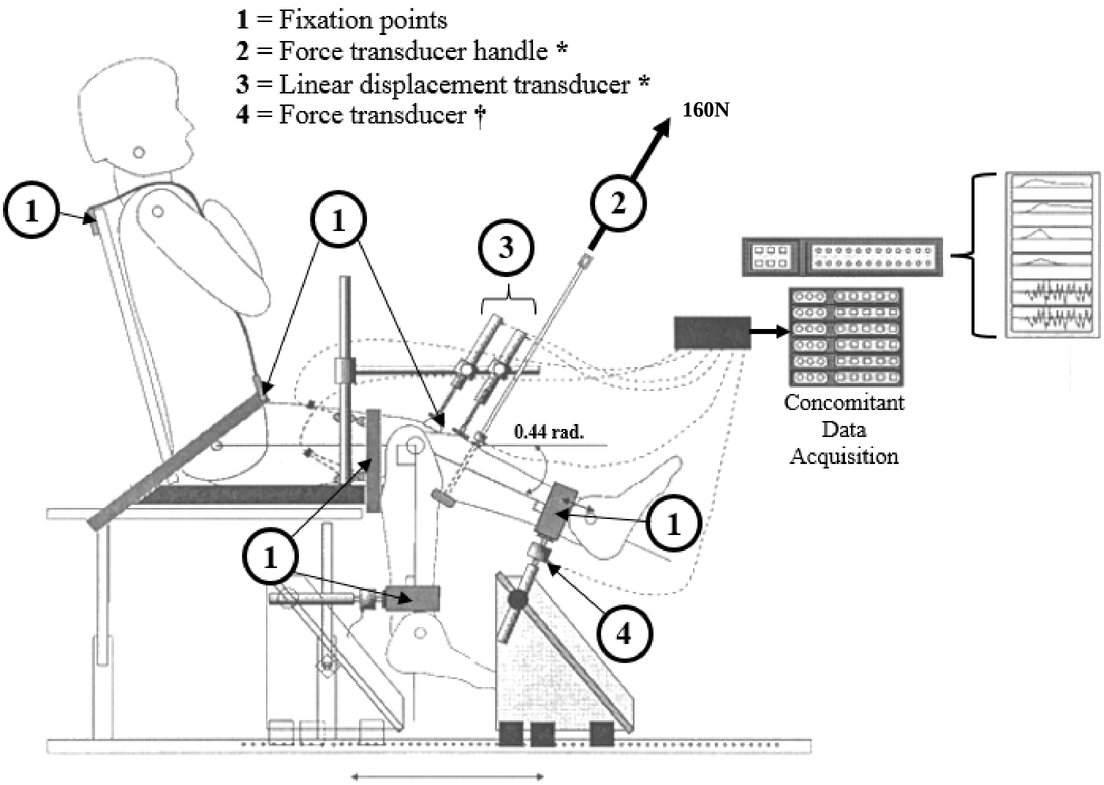
4.8.2.1 - Warm-up procedure

Prior to all assessments and procedures, patients undertook a standardised warm-up protocol that involved five minutes of cycle ergometry (90 watts for males; 60 watts for females, or as tolerated clinically by the patients) and a further five minutes of static stretching of the involved musculature of the lower limb.

4.8.2.2 - Patient and Dynamometer/Arthrometer Orientation

Every participant undertook a familiarisation session comprising habituation to the laboratory environment and assessment procedures. Participants were seated/secured on a custom-built dynamometer (Gleeson et al., 1992; Gleeson et al., 1996; Minshull at al., 2007) **(FIGURE 18**; next page**)**. These devices have been shown to be a reliable and valid means of assessment (Gleeson et al., 1992, Gleeson et al., 1996). The lever-arm on the dynamometer was attached to each leg in turn by means of padded ankle-cuffs and adjustable strapping, proximal to the lateral malleolus. The dynamometer and knee joint's axes of rotation were aligned as closely as possible. Adjustable strapping across the mid-thoracic spine, pelvis and posterior thigh, proximal to the knee, localised the action of the involved musculature

The dynamometer lever arms were attached to the lower legs at a functionally-relevant knee flexion angle of 25° (0° = full knee extension) associated with the greatest mechanical strain on ACL ligaments using the goniometer system (Li et al., 1999), for injured and contralateral (non-injured) legs. Assessments and the order of testing legs were undertaken in a random sequence that had been determined from a computer-generated list of numbers before each assessment/testing occasion (i.e., pre-surgery).



*Measurement of ACL laxity (ATFD)

†Measurement of neuromuscular performance (PF, RFD, EMD, SMP-FE)

FIGURE 18 - Participant and integrated measurement system for the assessment of knee ligamentous compliance (knee laxity) [ATFD, Anterior Tibio-Femoral Displacement]; neuromuscular performance outcomes of Peak Force [PF], Rate Of Force Development [RFD], Electromechanical Delay [EMD], and Sensorimotor Performance associated with Force Error [SMP-FE] (edited and adapted from Yates et al., 2016).

4.8.2.3 - Procedures for the Recording of Electromyography (EMG) responses

Estimates of Electromechanical Delay (EMD) were assessed by recording the surface Electromyography (EMG) activity associated with the m. biceps femoris and m. vastus lateralis muscles during each Maximal Volitional Muscle Action (MVMA) of contraction. The neuromuscular outcome measures to this thesis research (PF, EMD, and RFD) were later calculated from MVMA data (see p. 195). The m. biceps femoris and m. vastus lateralis were selected as important contributors to anterior tibio-femoral displacement and lateral rotation of the femur relative to the tibia since both processes have been implicated in ACL injury (Li et al., 1999).

Prior to participant orientation on the dynamometer, skin preparation including shaving, abrading (using fine sand paper) and degreasing (using an alcohol swab) of the skin over the belly of the biceps femoris was undertaken. Bipolar rectangular surface electrodes (self-adhesive, Ag/AgCl; 10 mm diameter; Unilect, UK) were applied longitudinally over the belly of the muscle parallel to the orientation of the muscle fibres **(FIGURE 19)**.

FIGURE 19 - The placement of surface bipolar electrodes for recording electromyography (EMG) activity on muscle belly of m. biceps femoris m. (left), and vastus Lateralis m. (right) (source: unpublished thesis; Bailey, 2015)

Two self-adhesive bi-polar surface electrodes (AgCl) were placed equidistant from the ischial tuberosity and the medial epicondyle of the femur with a fixed inter-electrode distance of 30 mm apart on both the injured and non-injured limbs. A third or 'reference' electrode was placed 30 mm lateral and equidistant from the recording electrodes parallel to the gap between the two detector electrodes. Electrode placement was standardised across assessment occasions, where appropriate, by mapping (using acetate paper) and measuring the position relative to anatomical landmarks and angiomas. Skin preparation quality was assessed using an impedance meter, with a resistance of less than 5 KΩ being acceptable (Basmajian, Gopal, and Ghista, 1985).

The raw unfiltered EMG signals, which incorporated minimal intrusion from induced currents associated with external electrical and electromagnetic sources and noise inherent in the remainder of the recording instrumentation, were passed through a differential amplifier (input impedance 10,000 MΩ, CMRR 100 dB, gain of 1000), filtered (Butterworth 2nd order; 1 kHz cut-off frequency) [Cambridge Electronic Design, UK]) and were converted, analogue-to-digital, at 2.5 kHz sample rate, ensuring a significant margin of reserve between the highest frequency expected in the EMG signal and the Nyquist frequency (Gleeson et al., 2001).

4.8.2.4 - Single-Leg Hop for distance

The Single-Leg Hop for distance is commonly used by physiotherapists to evaluate lower limb muscle strength, neuromuscular control, confidence in the injured limb, and the ability to tolerate loads related to sports-specific activities (Reid et al., 2007). Single-Leg Hop for distance test for distance has proved to be a reliable assessment tool during ACL rehabilitation (r = 0.92 to 0.98) (Hopper et al., 2002; Reid et al., 2007; Risberg et al., 1999).

All participants were instructed to start with the non-injured leg first. Participants were required to start from a single-leg stance on their assessed limb, before producing a hop for maximum distance with a controlled landing in a stable position. For Single-Leg Hop for distance to be considered successful, participant landing should be maintained for at least 2 seconds, therefore unsuccessful hops were repeated until deemed successful. No restriction was placed on arm movement, but was discouraged if possible, in order to provide assistance with balance if required to perform maximal efforts and landing balance. Distance jumped on a single leg was measured in centimetres from the toe at the start position to the heel at the landing position. Following two to three practice attempts, participants performed three maximal efforts, with the mean of the inter-trial replicates subsequently used for analysis. The same test administrator performed all measurements.

4.8.2.5 - Anterior Tibio-Femoral Displacement (ATFD)

Assessment of Anterior Tibio-Femoral Displacement (ATFD) was undertaken in the injured and non-injured legs. Assessments and the order of testing legs were undertaken in a random sequence that had been determined from a computer-generated list of numbers before each assessment/testing occasion (i.e., pre-surgery). The arthrometer system used in this assessment has been shown to be reliable and valid (Gleeson et al., 1996). The apparatus and patient orientation during the assessment is shown schematically in **FIGURE 20**. The knee joint was maintained at 25 degrees (0.44 radians) of flexion with foot positioning at 15 degrees (0.26 radians) of external rotation and 20 degrees (0.35 radians) of plantar flexion. A knee flexion angle of 25° (0° = full knee extension) is associated with the greatest mechanical strain on ACL ligaments (Li et al., 1999).

Instrumentation to measure ATFD consisted of two linear inductive displacement transducers (DCT500C, RDP Electronics Ltd., Wolverhampton, U.K., 0.025-m range). The latter incorporated spring-loaded plungers that were adjusted accurately in three planes to provide perpendicular attachment to the patella and tibial tubercle. During measurements, both transducers were secured to the skin surface using tape and they were able to move freely only in the anterior-posterior plane relative to the supporting framework. The instrument monitored only the relative motion between the patella and tibial sensors and so facilitated the exclusion of measurement artefacts caused by extraneous movements of the leg during the application of anterior displacement forces. Anterior force was applied in the sagittal plane and in a perpendicular direction relative to the tibia by an instrumented force-handle incorporating a load cell (Model 31E500N0, RDP Electronics Ltd., Wolverhampton, U.K., range 500N). This device was positioned behind the leg at a level 0.02 m inferior to the tibial tubercle. The transducers were interfaced to a computerised data acquisition system (Cambridge Electronic Design Ltd., U.K.). Calibrated data from all transducers were sampled at 2.5 kHz.

FIGURE 20 - Positioning of hand-held force transducers for measuring knee laxity (ATFD) (source: unpublished thesis; Bailey, 2015).

Measurements on each knee were preceded by three practice trials. During each measurement, patients were instructed to relax the musculature of the involved limb. The latter was verified by inspection of online EMG records of the activity of the m. biceps femoris and m. vastus lateralis. Rapid, but gentle, manual anterior-posterior drawer oscillations were used to facilitate relaxation and to establish a neutral tibio-femoral position from which all measurements were initiated. ATFD were calculated as the mean of three intra-session replicates of the net displacement of the patella and tibial tubercle transducers at an anterior tibial displacement force of 160 N applied in the sagittal plane, at a rate of $67 \pm 7\ N \cdot s^{-1}$, and was tolerated well by symptomatic patients (Gleeson et al., 1992; Gleeson et al., 2008). The same test administrator performed all measurements.

4.8.2.6 - Assessment of Sensorimotor Performance

Sensorimotor Performance (SMP) was assessed as the ability to scale volitional force precisely (Gleeson, 2001), and was as the Force Error (FE) arising from a task that required ‘blinded’ replication using the knee flexors of a target force (50% of pre-operative Peak Force [PF]). Sensorimotor Performance of the involved lower limb and its musculature was assessed by means of a force-matching task involving serial, brief, time-regulated muscle actions which involved a high-degree of voluntary recruitment of motor units. In this type of Sensorimotor Performance assessment, participants were required to reproduce a blinded prescribed 'target' force five times, which was set to be 50% of their individual capability for maximal voluntary muscle action (Peak Force at the specified angle of joint flexion), and associated with the expression of peak muscle power during dynamic muscular activations according to force-velocity and power-velocity relationships (Hill, 1938).

The task was a slow, self-regulated muscular activation (at a rate of ~200 $N \cdot s^{-1}$) with a standardised delay between the presentation of target and response (10 s). The extent of FE describes the bias or constant error around a target force and lower scores reflect better Sensorimotor Performance. Each assessment occasion included a familiarisation session of 15 practice efforts, in which each participant was familiarised with 50% of his/her pre-operative PF in a 'blinded' fashion (Pincivero et al., 2000). Participants were blinded to both the absolute level of the prescribed target force and the scale of measurement used to offer feedback. Feedback from the test administrator was offered as a standardised, arbitrary scale of measurement without units using terminology such as "20 high", "5 high" and "25 low", "15 low", depending on whether the outcome of a trial had been higher or lower than the target. Trials that showed outcomes within ± 2.0N of the target force (99% confidence limits of the technical error associated with the load cell) were described in feedback to the participant as having "no error" **(FIGURE 21).**

The patients indicated reproducing the target force precisely during assessments by fully relaxing the knee flexor or extensor musculature. For any given performance trial, force error in performance was computed using the generic expression: force error = ([observed performance score - target performance score] / target performance score)] · 100%). The mean error of three trials was used for subsequent data analysis.

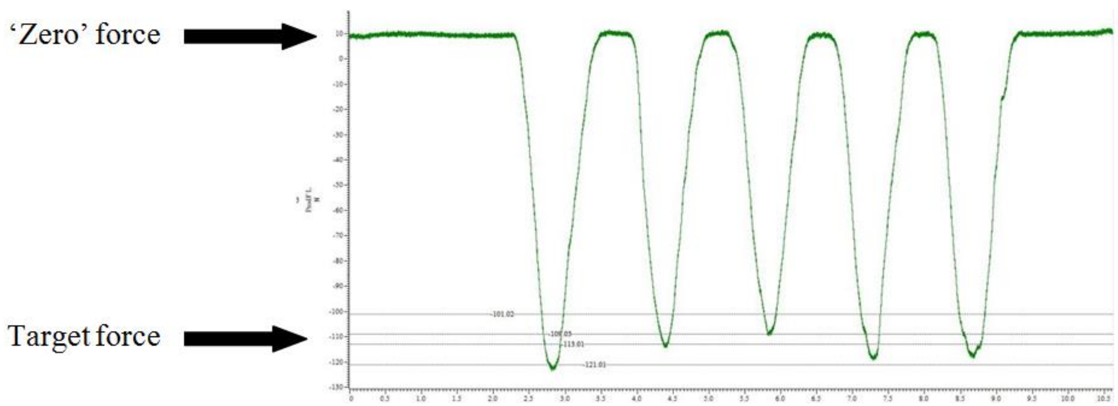


FIGURE 21 - The force-matching task: Five target-orientated, serial, brief, time-regulated muscle actions. The internal lines represent the targeted force (±2 N), while the external lines represent the ±10 N error (Source: Author's own diagram).

The level of Sensorimotor Performance was described by the extent of discrepancy observed between the prescribed target force and the participant's blinded reproduction of the target (constant Error or bias [CE%]) and expressed as a percentage relative to the target force (i.e., error in performance was computed using the generic expression: error = ((observed performance score - target performance score) / target performance score) · 100%). The required pattern of response from the participant in this assessment is shown in **FIGURE 21** (p. 192), where neuromuscular control assessment requires the participant to produce a Sensorimotor Performance involving target-orientated, serial, brief, time-regulated muscle actions.

Participants learnt the target force 'blinded' by undertaking a standardised series of trials in blocks (no more than 5 trials) using the involved musculature, where the aim was to match the target force as closely as possible. This procedure took place during the familiarisation session each subject had previously attended. Participants received standardised and contemporaneous verbal feedback only from the test administrator to facilitate further improvements in performance precision. In this way, participants were blinded to both the absolute level of the prescribed target force and the scale of measurement used to offer feedback. Participants were effectively learning to self-perceive the performance outcomes from an arbitrary scale of measurement without units. The same test administrator performed all measurements

Verbal feedback from the test-administrator was progressively withdrawn as the participants habituated and accommodated to the requirements of the task. This latter error interval corresponded approximately to the 99% confidence limits of the technical error associated with the load cell system and was the least significant difference in performance that could be reliably discerned by the naked eye of the test administrator from the monitor screen of the computer data acquisition system. The task was deemed to have been learned once the participant was capable of producing a criterion series of ten trials in which seven scores or more showed errors that were within ± 2.0 N of the 'blinded' target force. This level of performance was achieved, typically, once patients had undertaken between 90 and 150 practice trials. Retention of performance was verified briefly during warm-up and familiarisation trials prior to exercise interventions.

This type of assessment of Sensorimotor Performance involved serial, brief, time-regulated muscle actions and the capability to produce commensurate serial, brief controlling force responses. It may be considered the best representation of a situation to evaluate a functional task completed in a very short time where the athlete has very little time in which they could use feedback to moderate their force output and use afferent and efferent (neuromuscular) information to avoid injury (Gleeson et al., 1998). This type of response would be expected to involve stiffening of the joint system by muscle action. In particular**,** this situation might represent times within a game in which the stimuli of perceived disordered biomechanics may be registered consciously or subconsciously and the participant has perhaps two or three strides in which to lessen the mechanical stress on the joint system.

4.8.2.7 - Maximal Volitional Muscle Activation (MVMA)

Participants were seated/secured on a custom-built dynamometer (Gleeson et al., 1992; Gleeson et al., 1996; Minshull et al., 2007) **(**see **FIGURE 18**; p. 188 and **FIGURE 22** (below). Each participant completed a warm-up protocol of the lower limb musculature, as previously discussed. This consisted of three sets of five replicates of 50% Maximal Voluntary Muscle Activation (MVMA) and one contraction of 70% and 90% of the participant's maximal capability to facilitate physiological potentiation for the assessment of Peak Force (PF).

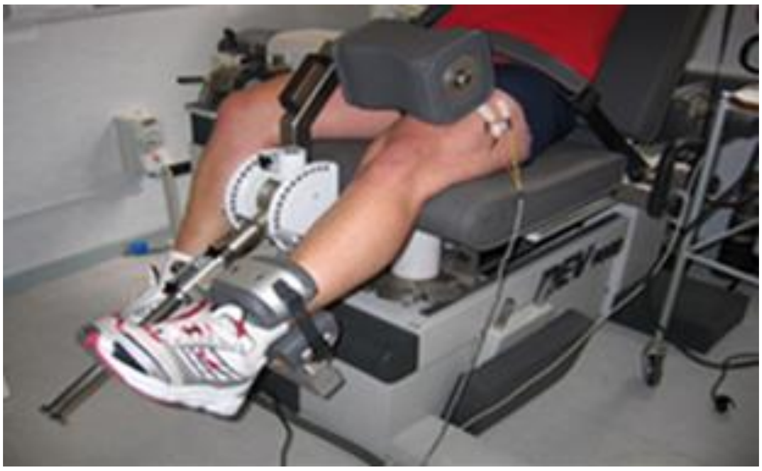


FIGURE 22 - Positioning of participant in dynamometer (Source: unpublished thesis; Bailey, 2015).

Following a series of sub-maximal warm-up muscle activations (as above), and after a verbal cue, an auditory signal was given randomly within 1-4 seconds and the participants attempted to activate their musculature as rapidly and forcefully as possible by attempting to extend or flex the knee joint as appropriate, against the immovable restraint (isometric) offered by the apparatus. Another auditory signal was given to the patient after 3 seconds of MVMA to cue neuromuscular relaxation. Intra-trial MVMA replicates were each separated by at least 10 seconds (Gleeson et al., 1996; Minshull, Gleeson, Eston. Bailey, and Rees, 2009; Minshull, Rees, and Gleeson, 2011). The MVMA of the knee extensor musculature was achieved in a similar manner.

Commercially-available software (Spike 2 software, version 5.16, Cambridge Electronics Design Ltd., U.K.) was used for all volitional data capture and interpretation. Volitional maximal PF was recorded as the greatest response from each of the three intra-session replicates of maximal isometric muscle activations (i.e., MVMA) of the knee flexors. The PF of the knee extensors musculature were achieved in a similar manner.

4.8.2.8 - Neuromuscular outcome measures (analysis of MVMA data)

Neuromuscular outcome measures (PF, EMD, and RFD) were calculated from analysis of maximal volitional muscle activation/contraction (MVMA) and associated recording of surface Electromyography Activity (EMG) with the m. biceps femoris (knee flexors) and m. vastus lateralis muscles (knee extensors). The mean of 3 maximal efforts with 10 seconds (Minshull et al., 2009) between was used to calculate all neuromuscular outcomes: PF (peak maximal force generate), RFD (average rate of force increase between 25% and 75% of PF) (Minshull, Eston, Rees, and Gleeson, 2012), and EMD (time delay between the onset of electrical activity and the onset of force, defined as the first points in time where the recorded signals exceeded consistently the 95% confidence limits of the background electrical-noise amplitude) (Minshull et al., 2007).

4.8.2.8a - Peak Force (PF)

Peak Force (PF) was calculated from analysis of MVMA data (see above) with the m. biceps femoris (knee flexors) and m. vastus lateralis muscles (knee extensors) for the injured and non-injured limbs. Volitional maximal PF was recorded as the greatest response from each of the three maximal effort (isometric) muscle activations/contractions. The mean of 3 maximal efforts was recorded **(**as illustrated in **FIGURE 23)**.

4.8.2.8b - Electromechanical Delay (EMD)

Electromechanical Delay (EMD) was computed as the mean response from three MVMA (see above) in which the time delay was between the onset of electrical activity (in milliseconds) and the onset of tension/force in skeletal muscle (Zhou, Carey, Snow, Lawson, and Morrison, 1998). The time region between the first vertical cursor and the second cursor (region: A) is associated with a muscle being in a relaxed state prior to voluntary activation **(FIGURE 24)**. The onset of electrical activity was defined as the first point in time at which the electrical signal exceeded consistently the 95% confidence limits of the isoelectric line associated with the background electrical noise amplitude and quiescent muscle, which was the first deviation of the recorded electrical signal that was congruent with physiological activation of the muscle. Similarly, the onset of muscle tension/force was defined as the first point in time at which the force record exceeded, consistently, the 95% confidence limits associated with the electrical noise amplitude of the load cells (region: B). The time in milliseconds (ms) was calculated within region B.

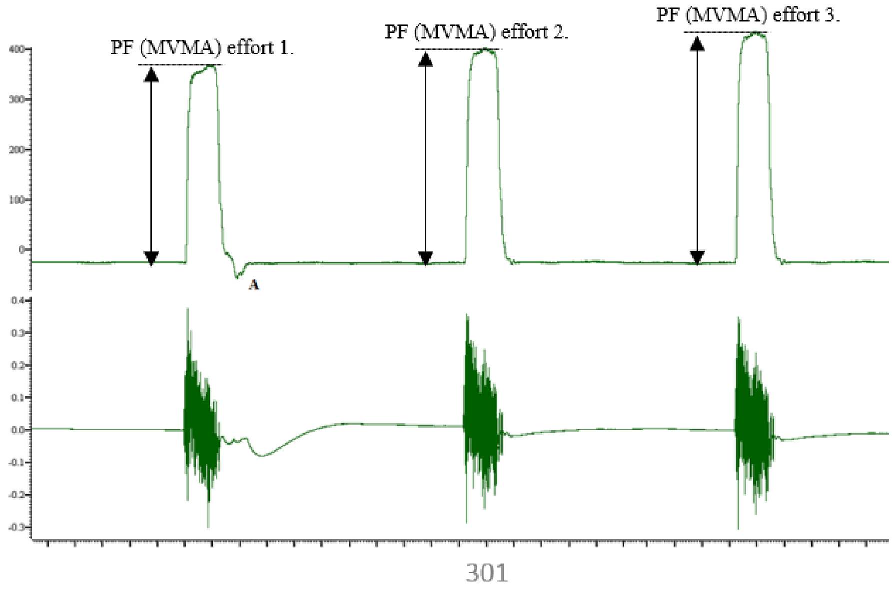


FIGURE 23 - Representation of a maximal voluntary muscle activation (MVMA) contraction of the knee flexor (A: upper trace lines: produced force) associated with Electromyography (EMG) activity (B: lower trace lines: electrical muscle activity) calculating Peak Force (PF). The mean of 3 maximal efforts recorded. <u>**NOTE**</u>**:** first MVMA (effort 1) would be excluded (see A) and would be required to be repeated (Source: Author's own diagram).

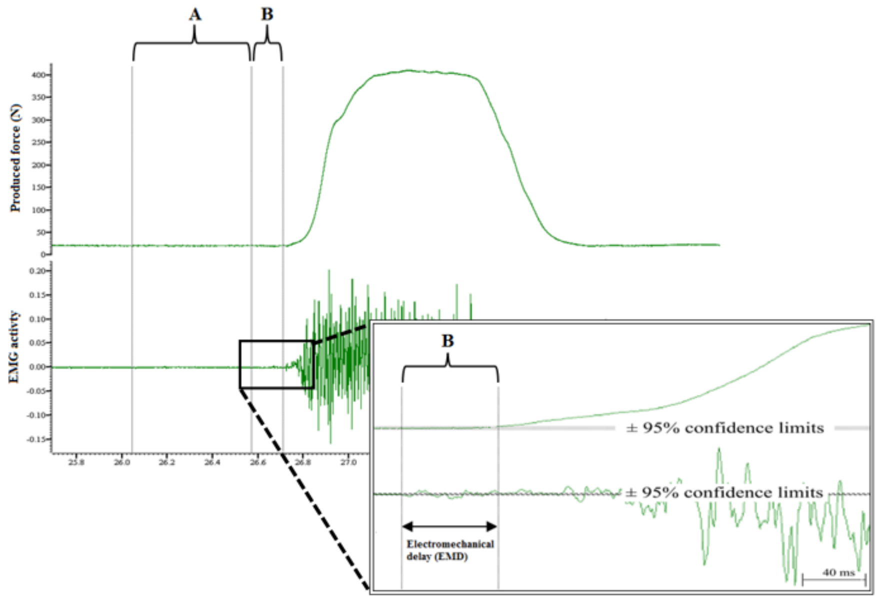


FIGURE 24 - Representation of a maximal voluntary muscle activation (MVMA) contraction of the knee flexor (A: upper trace lines: produced force) associated with Electromyography (EMG) activity (B: lower trace lines: electrical muscle activity) calculating Electromechanical Delay (EMD). The mean of 3 maximal efforts recorded and EMD score (ms) recorded (Source: Author's own diagram).

It has been proposed that EMD is influenced by several mechanisms and by skeletal structures, such as **(1 :)** the propagation of the action potential and the excitation-contraction coupling processes, and **(2 :)** the transmission muscle force along the series elastic component (Cavanagh and Komi, 1979). Numerous studies have shown that EMD time is related to the mechanical properties associated with muscle size and fibre type, shape of muscles and presence of muscular fatigue (Gabriel and Boucher, 1998; Kubo et al., 2001; Kubo et al., 2010). It can therefore be expected that EMD times will be altered due to muscle structure (Freddolini et al., 2013).

Cavanagh and Komi (1979) reported that normal EMD time for asymptomatic individuals ranged from 30 to 100 milliseconds (Vos, Mullender, and Van Ingen Schenau, 1990; Zhou, Lawson, Morrison, and Fairweather, 1995; Zhou, Mckenna, Lawson, Morrison, and Fairweather, 1996). The negative effects of deconditioning associated with ACL injury, reconstruction and graft type, combined with relatively long rehabilitation, all contribute to compromise EMD (Georgoulis et al., 2005; Ristanis et al., 2009). A decrease in EMD will increase the Rate of Force Development (see below) and is suggested to be critical to maintaining dynamic joint stability (Blackburn, Bell, Norcross, Hudson, and Engstrom, 2009), providing a mechanical response and stretch reflex that is required to protect the knee-joint. Hence, meaningful force levels can be initiated, assisting joint system stability in real-life situations (Ristanis et al., 2009; Minshull et al., 2007).

4.8.2.8c - Rate of Force Development (RFD)

Rate of Force Development (RFD) is defined as the slope of the force-time curve that occurs under isometric conditions of muscle contraction, and is the evaluation of the musculature force generation ability (Aagaard et al., 2001). Volitional RFD was calculated as the average rate of the mean of 3 maximal efforts with 10 seconds' rest between efforts (Minshull et al., 2009), with an average rate of force increase of between 25% and 75% of PF (Minshull et al., 2012).

The use of neuromuscular outcome/test of RFD has been acknowledged as a key outcome characterising the extent of neural drive to the muscle during rapid maximal muscle actions, and has also recently been acknowledged as an objective outcome/test to inform decisions regarding athletes' recovery and return to sports and may be sufficiently appreciable to be included in patients' assessments within clinical practice (Angelozzi et al., 2012). For example, one of the criteria for assessing patient readiness is the ability to reach at least 80-85% of the maximal strength in the injured limb versus the non-injured contralateral limb (Knezevic et al., 2014). In terms of explosive muscle strength, the duration of activating maximal muscle strength (300 milliseconds) is longer than the duration required for muscle to develop muscular strength (0-200 milliseconds), in either daily functional activities or sporting activities (Angelozzi et al., 2012), thus indicating that RFD maybe more crucial in muscle function than maximal muscle strength.

On the basis of these findings, RFD has, therefore, been used extensively to evaluate the capacity to generate muscular force at a rapid rate. If delayed RFD may have consequences and compromises the knee joint stability, this reduction may also contribute to causing neuro-muscular injury (Mebes et al., 2008). With regards to the reliability of RFD, Minshull et al., (2009) have evaluated intra-class correlation (RI) and CV% of RFD in magnetically-evoked and volitional knee performance on 12 asymptomatic (healthy adults); the results demonstrated RI reliability ranging from 0.81 ± 0.09, 20.6 of CV% and SEM of 24.5%.

4.9 - Statistical Analyses

All three studies share a similar experimental and assessment procedure as previously discussed[71], and each study will incorporate related statistical analyses (see below). However, any additional statistical analyses used in each study will be elaborated on in each associated methodological section. The software that was used for the statistical analysis in the thesis was Statistical Package for Social Sciences (SPSS; version. 20.0). All descriptive statistics (mean and standard deviation) are presented for all P-BOM and C-BOM variables (where appropriate).

At the outset, it was necessary to established whether all variables (i.e., P-BOMs and C-BOMs) had a normal distribution, and normality of all data variables (P-BOM: VAS [Pain], IKDC, KOOS, Lysholm, Performance Profile, and C-BOMs: Single-Leg Hop for distance, PF, EMD, RFD, ATFD, and SMP-FE) was evaluated separately for the experimental and control rehabilitation group. Normality of data in this trial was evaluated using Shapiro-Wilks (numerical test) and Q-Q plot (graphical test). These tests are designed for small to moderate sample sizes and have good power across a range of non-normal distribution. A variable of interest of more than 0.05 of *p* value for the null hypothesis of Shapiro-Wilk test (i.e. the population is normally distributed) was deemed normally distributed (i.e. there is no difference between the data examined and the normally distributed population).

The effects of the PPM intervention in patients undergoing ACLR surgery was assessed for each variable (P-BOMs: VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile, and C-BOM: Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) using separate ANOVAs, involving factors of group (PPM; CON) by leg (injured/non-injured) by assessment occasions (Pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) with repeated measures on the latter two factors. For the C-BOMs (i.e., PF, EMD, RFD, and SMP-FE), the knee flexors

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[71] Four studies are contained within this thesis and are reported in Study 1 **(Chapter 3: Systematic review;** p. 113), Study 2 **(Chapter 5: Correlation investigation;** p. 203), Study 3 **(Chapter 6: Reliability investigation;** p. 282), and Study 4 **(Chapter 7: Intervention RCT investigation**; p. 312**)**. All of the four studies share a similar experimental and assessment procedure and will be presented here.

(hamstrings) and knee extensors (quadriceps) of both injured and non-injured legs were assessed separately, where appropriate.

The potential for using analysis of covariance (ANCOVA) to statistically control for influential variables that could not be controlled experimentally within the study design, had been considered. As musculoskeletal injury rehabilitation outcomes are reportedly determined by a variety of anthropometric characteristics, orthopaedic-associated factors (Holla et al., 2013; Vincent et al., 2006; Lohmander et al., 2004) as well as environment and dose of exercise (Riseberg, 2004, Renstrom et al., 2008; Hewett, Myer, and Ford, 2006). Lastly, an investigation into the influence of anthropometric and orthopaedic-related factors (as above) would be necessary to statistically assess whether they affected the relationships amongst P-BOMs and C-BOMs at pre-surgery and across all rehabilitation phases. Factors like waiting time for surgery, which could not be experimentally-controlled within this study's design, and other influences like patients' anthropometric characteristics and orthopaedically-relevant factors have been shown to correlate to these clinical outcomes (Holla et al., 2013; Vincent et al., 2006; Lohmander et al., 2004) and are important aspects to consider.

For the examination of correlations between P-BOM and C-BOM, each variable was evaluated for linearity in accordance with the assumptions underpinning the use of correlation coefficients (Pearson product-moment correlation coefficient, r) used to assess the direction and strength of the linear relationships between pairs of variables (Mukaka, 2012). All correlations were examined and interpreted according to Hinkle et al., (2003) interpretations of correlations (no or negligible correlation [0.00 to 0.29 (0.00 - 0.29)]; low positive (negative) correlation [0.30 to 0.49 (-0.30 to - 0.49)]; moderate positive (negative) correlation [0.50 to 0.69 (-0.50 to - 0.69)]; high positive (negative) correlation [0.70 to 0.89 (-0.70 to - 0.89)]; and very high (negative) correlation [0.90 to 1.0 (-0.90 to - 1.0]) (**TABLE 6**; p. 126**).** The presentation of correlational relationships will be described descriptively. In addition, where possible, coefficient of determination (r^2) were to be included to predict the future outcomes of indices employed in this study.

4.9.1 - Power of the study

The sample size is also justified based on previous studies, for example, Gleeson et al., (2008) and Bailey (2015; unpublished thesis). A priori alpha levels were set at $p<0.05$. The experimental design offered an approximate 0.70 power of avoiding a type II error when employing a least detectable difference of 0.2 mm, 16N, 40N·s-1, 4ms, 2.5%, during comparisons of ATFD, PF, RFD, EMD, and SMP-FE, scores over time, respectively (Lipsey, 1990). Therefore, based on the latter least detectable difference (MCD), a scientifically verified internet-based sample size calculator was used to estimate the sample size of this study[72]. It was subsequently estimated that 50 participants would be needed [PPM (n = 25); CON rehabilitation groups (n = 25)] for appropriate experimental design sensitivity and statistical power involving random-allocation rehabilitations groups. Where selected assumptions underpinning analysis of variance had not been met, Greenhouse-Geisser adjustments of the degrees of freedom associated with the experimental and error variances were used.

4.10 - Ethical approval

This study thesis met the ethical standards suggested by Harriss and Atkinson (2009), and all content of chapters/studies was approved by the Ethics Committee for Human Testing by Queen Margaret University, Edinburgh, UK, and by the Shropshire area NHS Ethics Committee (REC reference: 05/Q2601/36) and had received scientific merit approval from the Research Committee of Robert Jones and Agnes Hunt Orthopaedic and District Hospital Foundation NHS Trust, UK. All information that was collected during the course of the study was kept strictly confidential, and the rights of all participants were protected.

4.11 - Data protection

A 'master copy' of individual identification numbers unique to each participant was stored in a safe place on site and was accessible only to the named key researcher. This identification number corresponded with the participant’s personal details and any participant information material and consent forms. This identification number was used throughout the research of the study to correspond with any scientific data collected, no personal or identifying information was used. All data was collected by the chief researcher throughout the clinical trial and data could only be accessed by the key researchers and associated collaborators.

All collated data was stored electronically on the designated research laptops and associated hard drives and back-up discs. The laptop and back-up discs were password-protected, including the master copy of the participants’ identification numbers (stored in a separate secure location within the physiotherapy clinic). Any published literature from this clinical trial did not include any names, only basic demographic data (i.e., subject’s number, age, sex, height, etc.). Written documentation and data were also stored in paper format in the participant’s medical notes as per normal clinical practice.

The storage and subsequent destruction of data are compliant with the Data Protection Act 1998. Written documentation and data have been stored in paper format in the participant’s medical

[72] Sample size calculator ‘http://sportsci.org/resource/stats/xSampleSize.xlsx’ (Hopkins, WG (2006). Estimating sample size for magnitude-based inferences: Sportscience 10, 63-70)

notes as per normal clinical practice. These will be destroyed 8 years after discharge as per the health care records policy at RJAH. All forms of data were securely kept in locked cabinets within locked rooms. Only the principal researchers and associated collaborators had permission to use and access the data. All information collected during the course of this research was kept strictly confidential and any information that could leave the hospital had the patients' names and addresses removed to ensure anonymity.

4.12 - Indemnity

Queen Margaret University, Edinburgh was the academic sponsor for this PhD research programme and has taken full responsibility and indemnity cover (Confirmation of Insurance, Marsh Ltd, Queen Margaret University, Edinburgh and Subsidiary Companies; Insurer: RSA, Insurance Certificate RTT153481, Public Liability 20M) for any harm that might come to participants as a result of the research design and management of each day. Similarly, Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS foundation has taken responsibility for any issues arising from the conduct of this research.

CHAPTER FIVE

STUDY 2

The Inter-correlations amongst Patient-Based and Clinician-Based Outcome Measures with Special Reference to the Performance Profiling Technique of Knees with Anterior Cruciate Ligament (ACL) Deficiency

5.1. - Introduction

International Classification of Functioning, Disability and Health (ICF) model **(**see **FIGURE 1**; p. 44**)** was developed by the World Health Organisation (WHO, 2016) to comprehensively evaluate function and disability by incorporating the two disability (medical and social) models (Jette, 2009). By integrating biological, social and individualistic components of health, forming a bio-psychological approach, the model has become a widely accepted framework by rehabilitation and medical professionals used as a means to communicate and speak in a common language across related professional disciplines in order to evaluate patients' overall health status[73] (Liang, Lew, Stucki, Fortin, and Daltroy, 2002). Moreover, this framework has offered rehabilitation practitioners a conceptual model and classification of the inclusion of the outcome measures (P-BOM[74] and C-BOM[75] outcomes) necessary to comprehensively assess the impact of ACL[76] injury (Logerstedt et al., 2010).

In summarising the ICF model, disability and functioning are viewed as outcomes of the interactions between health conditions (diseases, disorders and injuries) and contextual factors. Disability occurs when a health condition (i.e., ACL injury) leads to dysfunction at the two domain levels (**[1 :]** Body Functions and Structures and **[2 :]** Activities and Participation) indicating impairment (Body Functions and Structures), Activity Limitations (activities), or Participation restrictions, as mediated by both environmental and personal contextual factors (Jette, 2006). The use of P-BOMs and C-BOMs is important to comprehensively evaluate overall knee function from the perspective of both the patient and the physiotherapist, respectively.

With many P-BOMs and C-BOMs currently deployed in clinical practice by clinicians and researchers to assess patients' outcomes (Almangoush and Herrington, 2014), Study 1 **(Chapter 2: Systematic review)** is corroborated by the presented findings of the literature (Clarke, 2001; Fitzgerald et al., 2001; Pua et al., 2008), suggesting that each P-BOM and C-BOM potentially reflected important but separate aspect of clinical responses when evaluated concomitantly, and that they are not causally linked (Akker-Scheek et al., 2008; Reid et al., 2007). With particular reference to the findings of Study 1, only some statistically-significant correlations ($p< 0.05$) were found in the concomitant evaluation of P-BOMs and C-BOMs, and the outcome of this review suggested that the correlations found were not strong enough to be clinically relevant ($r \geq 0.70$)[77], that these

[73] Consult Logerstedt et al. (2010) for a comprehensive guide to the ICF disablement model which classifies and defines common musculoskeletal conditions using the World Health Organization's terminology related to impairments of body function and body structure, activity limitations, and participation restrictions, whilst also identifying appropriate outcome measures that can be deployed to evaluate outcome.

[74] Patient-Based Outcome Measures.
[75] Clinician-Based Outcome Measures.
[76] Anterior Cruciate Ligament (ACL).

[77] Cut-off values are based on suggestions of previous literature (Nunnally, 1978).

relationships lacked frequency across the 24-week rehabilitation period, and that they were hardly evident at 1 year and up to 5 years post-ACL injury or following ACLR surgery. Thus, the proxy use of P-BOMs as efficient substitutes to C-BOMs could not be seen, or recommended. Several clinical implications were thus speculated upon (see p. 117), mainly that clinicians should be cautious not to progress and plan their rehabilitative regime based on a single specific outcome measure, but should continue to deploy a battery of P-BOMs and C-BOMs to holistically evaluate patient outcomes and justify clinical decision-making (Michener, 2011; Lavoie et al., 2001).

Based on the literature (see p. 45) and Study 1 findings **(Chapter 3: Systematic review)**, the relationship between P-BOMs and C-BOMs cannot be ascertained with certainty in view of the diverse number of largely non-comparable P-BOMs/C-BOMs that were found, with no given P-BOM being consistently evaluated with the same C-BOMs. The strength of these relationships which remains unknown and relatively speculative therefore warrants further investigation. Although it could not be evaluated absolutely, an attempt was made to understand the degree of association or discordance between P-BOMs and C-BOMs evaluated concomitantly during 24 weeks of ACL rehabilitation. It would therefore be useful in future research to evaluate a range of P-BOMs and C-BOMs during the different rehabilitation phases as this could not be achieved from the results of this systematic review.

Since many correlational studies have, to date, only examined a small number of comparisons, the incorporation of a range of P-BOMs and C-BOMs measured simultaneously within a single clinical population would seem essential. Moreover, the select number of P-BOMs[78] and C-BOMs[79] that were found in the systematic review to be statistically significant ($p < 0.05$) and to demonstrate potential clinical relevance ($r \geq 0.70$) may require further validation, if possible. It would also be useful to evaluate relationships between muscle groups of both the injured and non-injured limbs as this correlational information was not obtained and could not be commented upon.

The inter-correlation between P-BOMs and C-BOMs should also be investigated separately in further research since this may allow conjecture over the number of rehabilitation outcome measures needed to accurately describe progression and help understand the hierarchy of importance of these outcome measures in order to correctly describe changes in functional capacity. Correlation coefficients and regression and their understanding are important components allowing a means to describe relationships among variables, to predict one variable from another, or to statistically support a causal inference. The use of correlational analyses allows researchers to reduce the information from unwieldy data to a single, easily understood number that varies from

[78] P-BOMs: Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance profile.
[79] C-BOMs: Hop [6m-timed], Stairs Hopple (timed), ATFD, PF, PT, TW, and EMD.

±1 to 0, for ease of comparison, where +1 signifies a likely strong (positive) correlation, while -1 signifies a likely strong (negative) association, and 0 signifies no relation between the variables (Malgady and Krebs, 1986). Investigations have used this method to evaluate the inter-correlations amongst P-BOMs, amongst C-BOMs, and amongst P-BOMs and C-BOMs together.

Firstly, ACL studies suggest a heterogeneity in the strength of relationships amongst P-BOMs. For example, the current literature reports a wide variety of correlation coefficients for the inter-correlations amongst P-BOMs: Briggs et al., (2009) showed differing correlations between the Lysholm versus IKDC ($r = 0.80$), and versus Short Form-12 ($r = 0.40$). Within a more recent study, Van Meer et al., (2013) evaluated the Lysholm versus IKDC ($r = -0.62$) and versus KOOS, assessing the sub-domain scores separately (Pain [$r = -0.68$], Symptoms [$r = -0.65$], Function [$r = -0.71$], Sport/rec [$r = -0.61$], and QoL [$r = -0.36$]). It is noteworthy that significant cut-off points for clinical relevance occur at $r \geq 0.70$[80]. Here, only the Lysholm versus IKDC ($r = 0.80$) satisfied this criterion. Noteworthy too, is that the square of the correlation coefficient (r^2) indicates the proportion of shared information when the statistical assumptions of association are considered, but not necessarily those required by prediction are satisfied (Malgady and Krebs, 1986).

An example of r^2 can be illustrated by the Van Meer et al., (2013) study, whereby the Lysholm and IKDC shared about 64% [$r^2 = (0.80)^2 = 0.64$] of the total variance indicating that about 36% of the variance of the Lysholm is not associated with that of the IKDC. Similarly, using the Lysholm versus KOOS sub-scales (reported above), the Lysholm versus KOOS (component scores) share a (r^2) from 12.7 to 50.4% of the total variance, suggesting that approximately 49.6 to 87.3% of the Lysholm is not predictable from the KOOS sub-domain scores. Similarly, a wide disparity of correlation coefficients (and r^2) has been found for C-BOMs evaluated concomitantly within ACLD and ACLR studies (Barber et al., 1992; Anderson et al., 1993; Jarvela, Kannus, Latvala, and Jarvinen, 2002; Kong et al., 2012).

The IKDC has, nonetheless, been the subject of more in-depth investigation than other P-BOMs which should include the Cincinnati, VAS (Pain), Oxford-12, WOMAC, KOOS, and Lysholm (Metsavaht et al., 2010; Agel and Laprade, 2009). It appears that the majority of previous research has assessed inter-correlations at short-term (1 year post-ACLR surgery) to long-term time frames from 5 to 25 years post-ACLR surgery (Cartwright-Terry et al., 2014; Briggs et al., 2009), and only a small number of studies have directly evaluated inter-correlations of P-BOMs within an ACL rehabilitation period (i.e., surgery to 6 months post-ACLR surgery) (Van Meer et al., 2013; Cartwright-Terry et al., 2014). Alongside this, few studies have yet to feature P-BOMs (i.e., IKDC, KOOS, Lysholm, Cincinnati, and Tegner) more commonly deployed in ACL research and practice

[80] As a matter of fact, no generally agreed "cut-off" points exist in the literature (Lexell and Downham, 2005), however, cut-off values are based on some suggestions of the previous literature (see Nunnally, 1978).

collectively within this time-frame (Johnson and Smith, 2001) warranting investigation.

5.2 - Aims and objectives

Since it is unknown to which outcome measures (P-BOMs or C-BOMs) are necessary for the delivery of a comprehensive patient assessment and the management of post-ACLR surgery (Phillips et al., 2000), Study 2 set out to describe and grasp more effectively the relationship between P-BOMs and C-BOMs; specifically the inter-correlations between: **(1:)** P-BOMs; **(2 :)** C-BOMs; and **(3 :)** P-BOMs and C-BOMs together, prior to ACLR surgery, and within acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) rehabilitation phases. This data could then be used to postulate the number of outcome measures needed to accurately describe progression, whilst revealing the hierarchy of importance of the outcomes which should in turn allow a more precise description of changes in functional capacity.

The first novel aspect of this study is the evaluation of the Performance Profile with the abovementioned three inter-correlations to reveal the correlational characteristics of the Performance Profile against commonly deployed P-BOMs and C-BOMs longitudinally across 24 weeks of rehabilitation (Gleeson et al., 2008; Yates et al., 2016), and allowing further commentary on the introduction of the Performance Profile into clinical practice. The second novel aspect is the investigation into the use of the contralateral (non-injured) limb as a control leg[81], with the evaluation including the knee flexors and knee extensors of both the injured and non-injured limbs since its evaluation in addition by the Performance Profile will allow a further understanding of the differences between the limbs.

The following hypotheses are anticipated (also see p. 61), firstly that the inter-correlation among P-BOMs (i.e., VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would demonstrate the highest strength of correlations compared to C-BOMs (i.e., Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE), since the P-BOMs used address similar facets and sub-components of dysfunction and disability (i.e., Pain, Symptoms, Function, QoL, etc.) within the inventory of questions asked, therefore greater convergence is to be expected. Secondly that the inter-correlation among C-BOMs (as above) at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would inter-correlate, but to a lesser extent due to the extremely disparate nature of the outcome measures used. Thirdly, that the inter-correlations among P-BOMs and C-BOMs measured concomitantly at pre-surgery and within subsequent rehabilitation phases would demonstrate a lesser strength of correlations compared to P-BOMs and C-BOMs evaluated in

[81] When attempting to identify levels of 'normal' or improved function brought about by ACLR surgery and subsequent rehabilitation, the use of the contralateral asymptomatic leg as a baseline and control is prevalent and indeed, was used in this way in Study 3 and Study 4.

isolation, since P-BOM and C-BOM outcomes quantify different aspects of recovery and function (disability versus impairment respectively) and are therefore reasoned to be weakly correlated (Akker-Scheek et al., 2008; Reid et al., 2007; Stratford and Kennedy, 2006; Fitzgerald et al., 2001).

The specific aims and objectives for this study are presented **TABLE 19**.

TABLE 19 - Study 2 aims and objectives.

CHAPTER FIVE	**Aims and Objectives**
Study 2 Correlational investigation	**To investigate the relationship amongst P-BOMs and C-BOMs within ACLD/ACLR patients.**[82] **(1)** To evaluate the inter-correlational relationship between the P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) prior to ACLR surgery, and within the acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) phases of rehabilitation. **(2)** To determine the inter-correlational relationship between the C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) outcome measures prior to ACLR surgery, and within the acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) phases of rehabilitation. **(3)** To establish the relationships among P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE), evaluated concomitantly, prior to ACLR surgery, and within the acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) phases of rehabilitation.

[82] The raw data/scores of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) from Study 4 **(Chapter 7: Intervention RCT investigation)** evaluated at assessment occasions (pre-surgery, weeks 6, 12, 24 weeks post-ACLR surgery) were used to formulate this correlation study (Study 2). The Performance Profiling Management (PPM) and contemporary rehabilitation (CON) group conditions were examined separately, to ascertain whether relationships among P-BOMs and C-BOMs differed between PPM and CON rehabilitation groups.

5.3 - Method

5.3.1 - Participants

Forty-six patients (41 Male [age at surgery: 31.7 ± 12.73 years (range: 16 to 63); Height: 176.27 ± 5.11 cm; body-mass: 80.53 ± 9.05 kg]; 5 female [age at surgery: 28 ± 11.77 years (range: 16 - 43); height: 162.1 ± 4.0 cm; body-mass: 64.24 ± 8.91 kg]; [Mean ± SD]) elected to undergo ACLR surgery (central third, bone-patella tendon-bone graft) at Robert Jones and Agnes Hunt Orthopaedic and District Hospital, Oswestry (UK). Participant age at surgery ranged from 16 to 58 years, with a mean age of 34.9 ± 11.1 years. All participants received ACLR surgery on average 336.0 ± 280.9 (range: 77-1694) days following injury date. Patients were treated by four consultant orthopaedic surgeons of similar experience and practice (>14 ACLR surgeries per month) using agreed and matched surgical procedures. All patients were treated by the same physiotherapist and followed a standardised and established program of rehabilitation used in current clinical practice (RJAH, 2007) **(APPENDIX 1**; p. 440**)**.

5.3.2 - Study Design and Procedure

This study investigates the raw data obtained from a randomised control trial **(Chapter 7: Intervention RCT investigation)** which deployed an experimental design involving a prospective random-allocation to group trial involving an experimental group (PPM: Performance Profile Management) group utilising a patient-centred and 'individualised' programme of musculoskeletal rehabilitation, with contralateral limb assessment, and manipulation checks. The study compared the effects of experimental post-surgical rehabilitation comprising 'individualised' PPM within contemporary clinical practice (control group [CON]). The experimental design was to ensure that the overall duration, volume, modes and intensity of exercise conditioning associated with 'individualised' rehabilitation was matched precisely to that within contemporary clinical practice.

5.3.3 - Experimental and Assessment Procedures

Experimental design was a large-scale exploratory/feasibility study - prospective and experimentally controlled, longitudinal design with repeated measures, which utilised a contralateral limb acting as a control, with a random selection of subjects - examining the Performance Profile (Butler and Hardy, 1992) which proposed greater utility in injury/recovery settings where greater perceived changes would occur (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Gleeson et al., 2005). Experimental design comprised a longitudinal comparison of the leg undergoing ACLR surgery with a contralateral limb acting as a control. Patients were assessed on 4 separate assessment occasions (2 weeks prior to surgery, 6, 12 and 24 weeks post-ACLR surgery) by P-BOMs[83] versus C-BOMs[84] (see below). The rehabilitation period was divided into an acute phase (0-6 weeks), intermediate phase (6-12 weeks), and late phase (12-24 weeks) of structured rehabilitation.

This section has been truncated, see general methods section **(Chapter 4: Methods**; p. 162**)** and randomised control trial **(Study 4: Chapter 7: Intervention RCT investigation**; p. 312**)** for more detailed information regarding study design and procedure. P-BOMs (VAS [Pain]; IKDC, KOOS, and Lysholm) are commonly deployed outcomes to assess patient-perspective following ACL injury (Almangoush and Herrington, 2014). The psychometric measurement characteristics of P-BOMs (IKDC, KOOS, and VAS [Pain]) are presented (see p. 173, 176, 178, and 180, respectively), and will be referred to within the discussion section of this study.

The P-BOMs (i.e., VAS [Pain], IKDC, KOOS, and Lysholm) (freely available to practitioners online) and C-BOMs (i.e., Single-Leg Hop for distance) are deployed at the rehabilitation and physiotherapy centre and are used throughout this thesis representing contemporary practice. In addition to these, and contrary to contemporary clinical practice, this thesis will examine the use of dynamometry, arthrometry and proprioceptive testing equipment in an attempt to understand the sensorimotor performance and neuro-musculoskeletal capabilities of patients during recovery and rehabilitation following their ACLR surgery (Gleeson et al., 1996; Gleeson et al., 2002; Minshull et al., 2007; Bailey et al., 2015; unpublished thesis).

The novel application of the Performance Profile to a symptomatic population (i.e., ACLR patients) has been proposed (Doyle and Parfitt, 1997; Weston et al., 2013), and the preliminary literature and empirical evidence, although limited, have provided the rationale and the novelty for this thesis to investigate the clinical utility and practical use of the Performance Profile (Gleeson et al., 2008; Yates et al., 2016) **(**see **Chapter 1**; p. 61**)**.

It was important to quantify each participants time spent in structured hospital-based and home/leisure-based rehabilitation. This was achieved by using the 7-Day Physical Activity Recall (7D-PAR) P-BOM (see p. 185) at four assessment occasions (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery), and all participants reporting number of minutes reported for each day for strength, cardiovascular and flexibility component performed and the intensity (Blair, 1985). The 7D-PAR outcome measure is reported to provide good validation of general-purpose measure of physical activity with good psychometric properties of reliability and in part validity (Soundy et al., 2007).

[83] Patient-Based Outcome Measures (P-BOMs).

[84] Clinician-Based Outcome Measures (C-BOMs).

5.3.4 - Statistical Analysis

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS; version 20.0 for Windows). All descriptive statistics (mean and standard deviation) are presented for all variables (P-BOM and C-BOM outcomes where appropriate).

At the outset, it was necessary to established whether all variables (i.e., P-BOMs and C-BOMs) had a normal distribution, and normality of all data variables (P-BOM: VAS [Pain], IKDC, KOOS, Lysholm, Performance Profile, and C-BOMs: Single-Leg Hop for distance, PF, EMD, RFD, ATFD, and SMP-FE) was evaluated separately for the experimental and control rehabilitation group. Normality of data in this trial was evaluated using Shapiro-Wilks (numerical test) and Q-Q plot (graphical test). These tests are designed for small to moderate sample sizes and have good power across a range of non-normal distribution. A variable of interest of more than 0.05 of *p* value for the null hypothesis of Shapiro-Wilk test (i.e. the population is normally distributed) was deemed normally distributed (i.e. there is no difference between the data examined and the normally distributed population).

For the examination of correlations between P-BOM and C-BOM, each variable was evaluated for linearity in accordance with the assumptions underpinning the use of correlation coefficients (Pearson product-moment correlation coefficient, r) used to assess the direction and strength of the linear relationships between pairs of variables (Mukaka, 2012). All correlations were examined and interpreted according to Hinkle et al., (2003) interpretations of correlations (no or negligible correlation [0.00 to 0.29 (0.00 - 0.29)]; low positive (negative) correlation [0.30 to 0.49 (-0.30 to - 0.49)]; moderate positive (negative) correlation [0.50 to 0.69 (-0.50 to - 0.69)]; high positive (negative) correlation [0.70 to 0.89 (-0.70 to - 0.89)]; and very high (negative) correlation [0.90 to 1.0 (-0.90 to - 1.0]) **(TABLE 6;** p. 126**).** The presentation of correlational relationships will be described descriptively. In addition, where possible, coefficient of determination (r^2) were to be included to predict the future outcomes of indices employed in this study.

Throughout the study, four respective sections (i.e., pre-surgery and rehabilitation [acute, intermediate and late] phases) will be evaluated with three separate inter-correlations. The first inter-correlations were among P-BOMs, proceeded by inter-correlation among C-BOMs, and finally, a third inter-correlation is among P-BOMs and C-BOMs together. Each inter-correlation (as above) is computed at each pre-surgery, and at acute, intermediate, and late phases of rehabilitation.

The VAS (Pain), IKDC, and Lysholm consisted of a total/aggregated score, while the KOOS consisted of five sub-domains scores (i.e., Symptoms, Pain, Function, Sport and Recreation, and Quality of Life). Using sub-domain scores has been reported to potentially enhance the clinical interpretation of outcomes found than compared to a total score which has yet been validated (Collins et al., 2011). The Performance Profile was the sole P-BOM that requested patients to rate perceived current state separately on the injured and non-injured leg and was evaluated separately. A priori alpha levels were set at $p < 0.05$.

5.4 - Results

The raw data/scores of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) from Study 4 **(Chapter 7: Intervention RCT investigation)** evaluated at assessment occasions (pre-surgery, weeks 6, 12, 24 weeks post-ACLR surgery) were used to formulate this correlation study (Study 2)[85]. It was therefore necessary to determine if the PPM and CON rehabilitation groups demonstrated any significant differences amongst P-BOMs and C-BOMs, demographically-, anthropometrically-, and orthopaedically-relevant characteristics at pre-surgery. Baseline group mean comparisons were performed using separate one-way ANOVAs, involving independent groups (PPM and CON), on each dependent variable of interest.

Analyses of group means for experimental (PPM) and control (CON) rehabilitation conditions for P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile [in summary, $F_{(1,44}$ = 0.08 to 0.2; p > 0.05, *ns*]), C-BOMs (Single-Leg Hop for distance, ATFD, PF, EMD, RFD, and SMP-FE [in summary, $F_{(1,44}$ = 0.1 to 0.8; p > 0.05, *ns*]), together with anthropometric and orthopaedic-related factors (height [cm], body-mass [kg], time from injury to surgery [days], METs, and unstructured physical activity [strength, flexibility, and cardiovascular conditioning (time) [in summary, $F_{(1,44}$ = 0.4 to 1.7; p > 0.05, *ns*]) were shown to be statistically similar at pre-surgery (baseline). Only age at surgery proved to be an exception [$F_{(1, 44)} = 4.3$; p< 0.04], with age of the PPM group (35.0 ± 14.2 years) being significantly greater than that of the CON group (27.6 ± 9.5 years). Although age at surgery showed significant differences between groups, correlational analyses showed age had no significant relationship with primary outcome variables (IKDC), other key P-BOMs and C-BOMs, either at pre-surgery (baseline) or during subsequent assessment occasions, and, suggesting that the wouldn't be influential in subsequent analyses. Therefore, the amalgamation of the population of patients undergoing ACLR prior to surgical reconstruction (pooled PPM/CON rehabilitation groups) totalling 46 participants offered greater statistical strength and better identified possible relationships among the P-BOM and C-BOM outcomes. For the remaining sections (acute, intermediate, and late phases of rehabilitation), the PPM and CON rehabilitation groups were evaluated separately[86].

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[85] Preliminary analysis of Study 4 **(Chapter 7: Intervention RCT investigation)** data, including the normality and assumptions etc., were evaluated. This information is not reported here, however, consult p. this chapter for more information.

[86] The novelty of this study (addressing the secondary clinical research question: p. 53) is the evaluation of the contralateral (non-injured) limb and knee flexors and knee extensors of both the injured and non-injured limbs. Indeed, the inclusion of a non-injured limb has yet to be thoroughly presented in correlational studies to date

The results section will be divided into four sections: pre-surgery, acute phase (0-6 weeks), intermediate phase (6-12 weeks), and late phase (12-24 weeks), respectively **(FIGURE 25)**. Within each section (i.e., pre-surgery), three separate inter-correlations were computed (**[1 :]** inter-correlations among P-BOMs (denoted '**A**'), **[2 :]** inter-correlations among clinician-based outcome measures (denoted '**B**'), and **[3 :]** inter-correlations among P-BOMs and C-BOMs together (denoted '**A** and **B**').

5.4.1 - Inter-correlation amongst P-BOMs prior to ACLR surgery

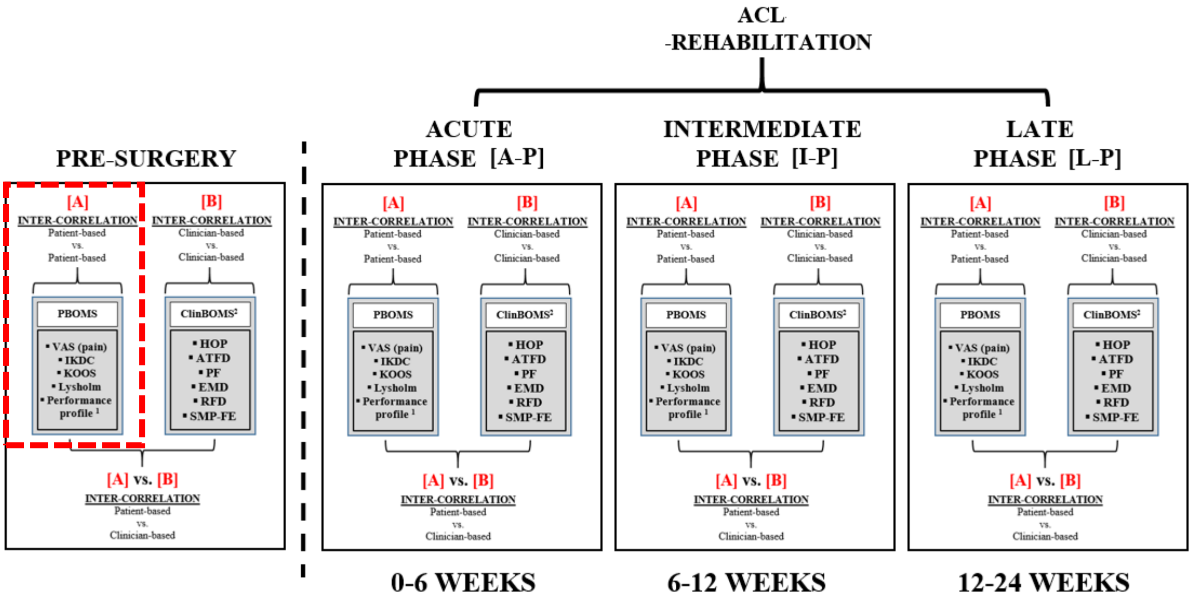

FIGURE 25 - Overview of inter-correlations computed among P-BOMS at pre-surgery for combined PPM and CON rehabilitation group (n = 46).

The relationship among P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile)[87] at pre-surgery were computed for CON/PPM (n = 46). With the amalgamation pooled PPM and CON rehabilitation groups at pre-surgery, and for each inter-correlation reported, it is

(Sernet et al., 1999) and its evaluation will allow an understanding of the differences between the limbs. Although a degree of physiological de-conditioning of the non-injured leg is expected due to altered physiological loading in the period between injury and surgery, the inclusion of this leg nevertheless represents a best estimate of a reference (baseline) for performance and functional capability following ACL injury (Gleeson et al., 2008; Bailey et al., 2015).

[87] The VAS (Pain), IKDC, and Lysholm consisted of a total/aggregate scores, whilst the KOOS consisted of five sub-scale scores (i.e., Symptoms, Pain, Function, Sport and Recreation, and Quality of Life). Using sub-scale scores has been reported to potentially enhance the clinical interpretation of outcomes found than compared to a total score for the KOOS outcome measure, as yet a total score has been validated (Collins et al., 2011).

necessary to report descriptive statistics (Mean ± SD) for demographic data and P-BOMs for PPM and CON rehabilitation groups separately **(TABLE 20)**.

A total of 28 correlations were included in the analysis **(**see **TABLE 21**; p. 216**)**. From a total of 28 correlations, 24/28 (86%) correlations were found to be significant at p< 0.05 (x5)[88], p< 0.01 (x3), and p< 0.001 (x16) significance levels. This first computed inter-correlation within P-BOMs illustrates the first evidence convergence between P-BOMs. For the IKDC, 6 correlation coefficients were found for the VAS (Pain) (r = -0.41; p< 0.01; n= 46) and amongst KOOS component scores (r = -0.32 to -0.59; p< 0.05; n =46). In the latter, the inter-correlation among IKDC versus KOOS component scores [Symptoms (r = -0.58; p< 0.001, n=46); Pain (r = -0.59; p< 0.001; n=46); Function (r = -0.53; p< 0.001; n=46); QoL (r = -0.52; p< 0.001; n=46); and Sport/rec (r = -0.32; p< 0.05)] were found; suggesting the KOOS component (Symptoms, Pain, Function, and QoL) scores were moderately (negatively) correlated with the IKDC. The KOOS component (Sport/rec) score had been found a low (negatively) correlation with IKDC **(TABLE 6**; p. 126**)**. With regards to VAS (Pain) versus IKDC inter-correlation further suggesting a low (negative) correlation being found.

For the Lysholm, 5 correlation coefficients were found. The Lysholm versus IKDC (r = 0.65; p< 0.001; n=46) and KOOS component scores (as below) ranged (r) from -0.45 to -0.60 (p< 0.01; n= 138); suggesting the IKDC was moderately (positively) correlated with the Lysholm **(TABLE 6**; p. 126**)**. In the latter, only four of the KOOS component scores were found to be significant versus Lysholm [versus Symptoms (r = -0.45; p< 0.001; n=46); pain (r = -0.60; p< 0.001; n=46); Function (r = -0.57; p< 0.001; n=46); and QoL (r = -0.45; p< 0.001; n=46)]; suggesting KOOS component (Symptoms and QoL) scores had a low (negative) correlation with the IKDC. However, for the KOOS component (Pain and Function) scores were slightly higher being moderately (negatively) correlated **(TABLE 6**; p. 126**)**.

For the VAS (Pain), 3 correlations were found for the KOOS component scores ranging (r) from 0.29 to 0.42 (p< 0.05; n=138). More specifically, KOOS component of Pain (r = 0.42, p< 0.01; n=46), Symptoms (r = 0.36, p< 0.01; n=46), Function (r = 0.29, p< 0.05; n=46) scores suggested no or negligible relationships found for the KOOS (Function) versus VAS (Pain). Furthermore, a marginally higher relationship was found among the KOOS component (Pain and Symptoms) scores versus VAS (Pain); suggesting low (positive) relationships **(TABLE 6**; p. 126**)**.

For the inter-correlations among the KOOS component scores, a total of 10 correlation coefficients were found (ranging from [r=] 0.37 to 0.91 (p< 0.05; n = 46); suggesting a wide disparity of correlation coefficients varying from a low to very high (positive) relationship. Noticeably, the highest correlation coefficient found among the inter-correlation of KOOS

[88] x = number of significant correlation coefficients found at certain level of significance (i.e., p< 0.001)

component scores was reported for the KOOS (Pain) versus KOOS (Function) ($r = 0.91$; $p < 0.001$; $n = 46$); suggesting a very high (positive) inter-relationship **(TABLE 6**; p. 126**)**. In the latter, it could be expected that a patient rating of pain would be related to function. For example, if no pain was present (scored appropriately by KOOS sub-section as minimal) it would be speculated that function capability would not be inhibited, and vice-versa for if pain was present.

With regards to the Performance Profile, this P-BOM is the only outcome which utilised a separate score for the injured and non-injured limbs. No significant correlations ($p < 0.05$) were found for the Performance Profile (mean of 10-items) at pre-surgery for the injured and non-injured limbs versus any other P-BOMs (i.e., VAS (Pain), IKDC, KOOS, and Lysholm).

TABLE 20 - All significant ($p < 0.05$) correlation coefficients (Pearson product moment correlation [r]) among inter-correlation of P-BOMs (VAS [Pain], IKDC, KOOS, and Lysholm) at pre-surgery (pooled PPM/CON rehabilitation groups) (n = 46). The interpretation of the strengths of correlation coefficients reported as suggested by Hinkle et al., (2003) classification system (see p. 138)[89].

P-BOMs.	vs.	P-BOMs.	Correlation Coefficient.	Significance level.	Hinkle et al., (2003) interpretation.
IKDC	vs.	KOOS (Function)	-0.53	0.001	Moderate (negative)
IKDC	vs.	KOOS (Pain)	-0.59	0.001	Moderate (negative)
IKDC	vs.	KOOS (Qol)	-0.52	0.001	Moderate (negative)
IKDC	vs.	KOOS (Sport/Rec)	-0.59	0.05	Moderate (negative)
IKDC	vs.	KOOS (Symptoms)	-0.58	0.001	Moderate (negative)
IKDC	vs.	Lysholm	0.65	0.001	Moderate (positive)
KOOS (Function)	vs.	KOOS (Qol)	0.44	0.001	Low (positive)
KOOS (Function)	vs.	KOOS (Sport/Rec)	0.58	0.001	Moderate (positive)
KOOS (Pain)	**vs.**	**KOOS (Function)**	**0.91**	**0.001**	**Very high positive)**
KOOS (Pain)	vs.	KOOS (Qol)	0.42	0.01	Low (positive)
KOOS (Pain)	vs.	KOOS (Sport/Rec)	0.55	0.001	Moderate (positive)
KOOS (Sport/Rec)	vs.	KOOS (Qol)	0.62	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (Function)	0.61	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (Pain)	0.66	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (Qol)	0.37	0.01	Low (positive)
KOOS (Symptoms)	vs.	KOOS (Sport/Rec)	0.37	0.01	Low (positive)
Lysholm	vs.	KOOS (Function)	-0.57	0.001	Moderate (negative)
Lysholm	vs.	KOOS (Pain)	-0.60	0.001	Moderate (negative)
Lysholm	vs.	KOOS (Qol)	-0.45	0.001	Low (negative)
Lysholm	vs.	KOOS (Symptoms)	-0.45	0.001	Low (negative)
VAS (Pain)	vs.	IKDC	-0.41	0.01	Low (negative)
VAS (Pain)	vs.	KOOS (Function)	0.29	0.05	No or negligible
VAS (Pain)	vs.	KOOS (Pain)	0.42	0.01	Low (positive)
VAS (Pain)	vs.	KOOS (Symptoms)	0.36	0.01	Low (positive)

[89] The remaining correlational data from here on can be seen in **APPENDIX 8 (**p. 559).

		VAS (pain)	IKDC	Lysholm	KOOS (symptoms)	KOOS (pain)	KOOS (function)	KOOS (sport/rec)	KOOS (QoL)	Performance profile (injured)	Performance profile (non-injured)
	VAS (pain)										
	IKDC	**-.414‡** .01									
	Lysholm	-.180 .23	**.650⁝** .001								
KOOS	(symptoms)	**.365†** .01	**-.586⁝** .001	**-.458⁝** .001							
KOOS	(pain)	**.421‡** .01	**-.599⁝** .001	**-.601⁝** .001	**.662⁝** .001						
KOOS	(function)	**.295†** .05	**-.531⁝** .001	**-.572⁝** .001	**.618⁝** .001	**.912⁝** .001					
KOOS	(sport/rec)	.18 .24	**-.325†** .05	-.256 .09	**.372†** .01	**.559⁝** .001	**.588⁝** .001				
KOOS	(QoL)	.01 .93	**-.528⁝** .001	**-.452⁝** .001	**.374†** .01	**.428‡** .01	**.442⁝** .001	**.627⁝** .001			
Performance profile	(injured)	-.06 .69	.035 .81	-.05 .76	.28 .06	.18 .23	.17 .25	.18 .23	.03 .86		
Performance profile	(non-injured)	-.12 .43	.225 .13	.12 .43	.09 .56	-.09 .55	-.02 .89	.04 .80	-.11 .47	.18 .22	

TABLE 21 -Inter-correlation among P-BOMs (VAS [Pain], KOOS [component scores], Lysholm, and Performance Profile) at pre-surgery (pooled PPM/CON rehabilitation groups) (n = 46)[90].

[90] The top number in each matrix block refers to correlation coefficient value computed for each inter-correlation (i.e., r = 0.56), and the number below is the statistical significance value reported for this interaction (i.e., p< 0.01). For ease of interpretation all statistically significant correlation coefficients have been highlighted in bold and the following have been used († significant correlation at p< 0.05; ‡ significant correlation at p< 0.01; and ⁝ significant correlation at p< 0.001 significance levels).

5.4.2 - Inter-correlation amongst C-BOMs prior to ACLR surgery

5.4.2a - The relationship among C-BOMs at pre-surgery for knee flexors (injured limb) for pooled PPM and CON rehabilitation groups (n = 46)

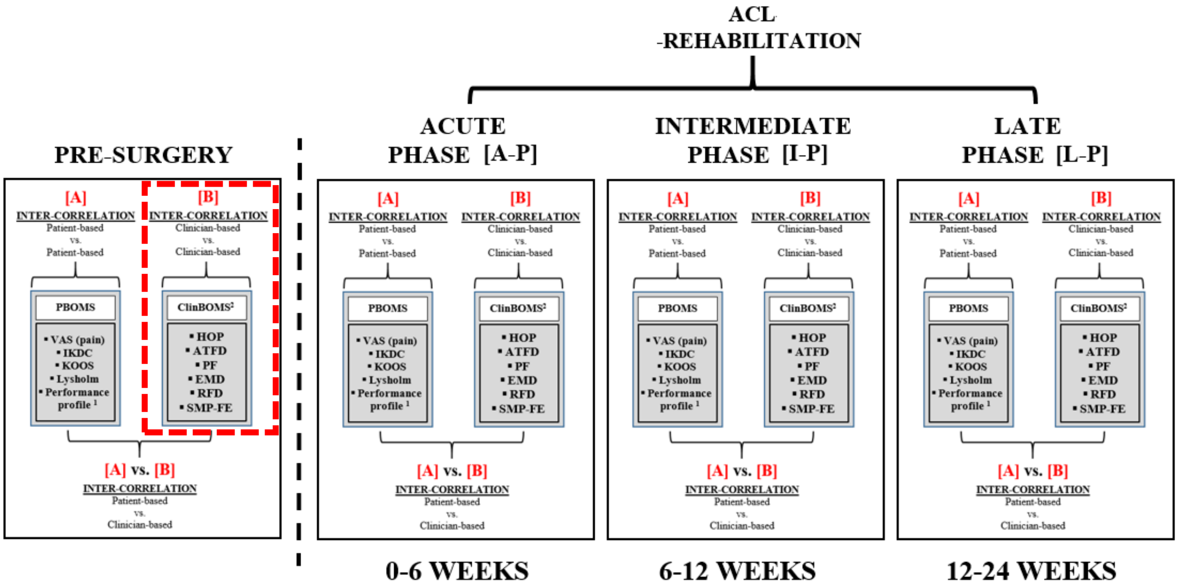

FIGURE 26 - The relationship among C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) were computed at pre-surgery for the injured and non-injured limbs for the knee extensors and knee flexors separately (n = 46).

A total of 15 correlation coefficients was found for all C-BOMs **(TABLE 22**; p. 220). From this total of 15 correlations, 2/15 (13%) correlation coefficients were found to be significant at p< 0.01 (x2) level. PF was significantly correlated versus the same limb (injured side) for the Single-Leg Hop for distance (r = 0.43; p< 0.01; n = 46); suggesting a low (positive) relationship between PF and this hop outcome **(TABLE 6**; p. 126**)**. In the remaining significant correlation, SMP-FE was significantly correlated with RFD (r = -0.39; p< 0.01; n = 46); suggesting a low (negative) relationship between SMP-FE and RFD **(TABLE 6**; p. 126**)**. No other significant relationships were found for Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE at pre-surgery for knee flexors for the injured-limb.

5.4.2b - The relationship among C-BOMs at pre-surgery for knee extensors (injured limb) for pooled PPM and CON group conditions (n = 46)

A total of 15 correlation coefficients was found for all C-BOMs. From this total of 15 correlations, 1/15 correlations were found to be significant at p< 0.001 (n = 46) level **(**

TABLE 23; p. 220**)**. PF was significantly correlated versus Single-Leg Hop for distance ($r = 0.57$; $p < 0.001$, $n = 46$); suggesting a moderate (positive) relationship between PF and Single-Leg Hop for distance **(TABLE 6**; p. 126**)**. No other significant relationships were found for Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE at pre-surgery for knee extensors of the injured limb.

5.4.2c - The relationship among C-BOMs at pre-surgery for knee flexors (non-injured limb) for pooled PPM and CON rehabilitation group (n = 46)

A total of 15 correlation coefficients was found with all C-BOMs **(TABLE 24**; p. 217**).** From this total of 15 correlations, 2/15 (13%) correlations were found to be significant at $p < 0.05$ level. PF was significantly correlated versus Single-Leg Hop for distance (non-injured limb) ($r = 0.33$; $p < 0.05$; $n = 46$); suggesting a low (positive) relationship between PF and Single-Leg Hop for distance **(TABLE 6**; p. 126**)**. In the remaining significant correlation found, SMP-FE was correlated versus PF ($r = -0.33$; $p < 0.05$; $n = 46$); suggesting a low (negative) relationship between SMP-FE and PF **(TABLE 6**; p. 126**)**. No other significant relationships were found for Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE at pre-surgery for knee flexors for the non-injured limb.

5.4.2d - The relationship among C-BOMs at pre-surgery for knee extensors (non-injured limb) for pooled PPM and CON rehabilitation group (n = 46)

A total of 15 correlation coefficients was found with all C-BOMs **(TABLE 25**; p. 217). From this total of 15 correlations, 3/15 (27%) correlations were found to be significant at $p < 0.05$ ($n = 46$) level. PF was significantly correlated versus Single-Leg Hop for distance ($r = 0.33$; $p < 0.05$, $n = 46$); suggesting a low (positive) relationship **(TABLE 6**; p. 126**)**. SMP-FE was significantly correlated versus Single-Leg Hop for distance ($r = 0.36$; $p < 0.01$; $n = 46$); suggesting a low (positive) relationship between Single-Leg Hop for distance and SMP-FE. In the remaining significant correlation, SMP-FE was significantly correlated versus RFD ($r = 0.47$; $p < 0.001$; $n = 46$); suggesting a low (positive) relationship between SMP-FE and RFD **(TABLE 6**; p. 126**)**. No other significant relationships were found for Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE at pre-surgery for knee extensors of the non-injured limb.

TABLE 22 - Inter-correlation among C-BOMs (Single-Leg Hop for distance (injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee flexors of the injured limb (n = 46).

	Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
Single-leg-hop (distance)						
ATFD	-.07 .65					
PF	**.43‡ .003**	-.05 .73				
RFD	.19 .21	.03 .86	.17 .27			
EMD	.10 .49	.24 .11	.03 .86	-.03 .84		
SMP-FE	.20 .18	.00 .98	-.15 .32	**.39‡ .008**	.16 .29	

TABLE 23 - Inter-correlation among C-BOMs (Single-Leg Hop for distance (injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee extensors of the injured limb (n = 46).

	Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
Single-leg-hop (distance)						
ATFD	.17 .26					
PF	**.33† .02**	.22 .13				
RFD	.17 .27	.05 .75	.22 .13			
EMD	-.20 .19	-.12 .41	-.16 .28	-.13 .38		
SMP-FE	.09 .57	-.13 .40	**-0.33 .02†**	.11 .45	.14 .35	

TABLE 24 - Inter-correlation among C-BOMs (Single-Leg Hop for distance [non-injured], ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee flexors of the non-injured limb (n = 46).

	Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
Single-leg-hop (distance)						
ATFD	.17 .26					
PF	**.33† .02**	.22 .13				
RFD	.17 .27	.05 .75	.22 .13			
EMD	-.20 .19	-.12 .41	-.16 .28	-.13 .38		
SMP-FE	.09 .57	-.13 .40	**-0.33 .02†**	.11 .45	.14 .35	

TABLE 25 - Inter-correlation C-BOMs (Single-Leg Hop for distance (non-injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee extensors of the non-injured limb (n = 46).

	Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
Single-leg-hop (distance)						
ATFD	.17 .26					
PF	**.33† .03**	.22 .13				
RFD	.26 .08	-.05 .76	-.05 .74			
EMD	-.06 .71	.17 .26	-.07 .63	-.18 .22		
SMP-FE	**.36* .01†**	.10 .51	-.17 .27	**.47‡ .001**	-.15 .31	

NOTE: The top number in each matrix block refers to correlation coefficient value computed for each inter-correlation (i.e., r = 0.56), and the number below is the statistical significance value reported for this interaction (i.e., p< 0.01). For ease of interpretation all statistically significant correlation coefficients have been highlighted in bold and the following have been used († significant correlation at p< 0.05; ‡ significant correlation at p< 0.01; and ⁝ significant correlation at p< 0.001 significance levels).

5.4.3 - The relationship among P-BOMs versus C-BOMs at pre-surgery

5.4.3a - The relationship among P-BOMs versus C-BOMs at pre-surgery for knee flexors (injured limb) for pooled PPM and CON rehabilitation groups (n = 46)

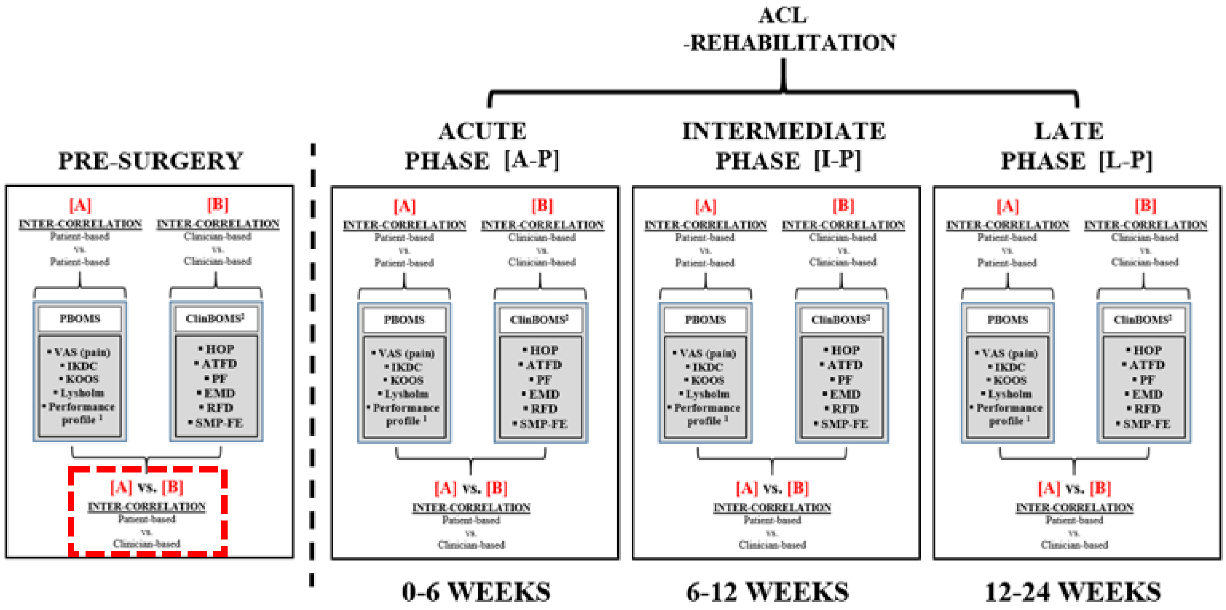

FIGURE 27 - The relationship amongst P-BOMs versus C-BOMs computed at pre-surgery for the injured and non-injured limbs for the knee extensors and knee flexors separately (pooled PPM/CON rehabilitation groups) (n = 46).

The relationship among P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) were computed at pre-surgery for the injured and non-injured limbs for the knee extensors and knee flexors (n = 46). A total of 54 correlation coefficients was found by evaluating P-BOMs and C-BOMs outcome/variables (as above) for the knee flexors of the injured limb**.** From a total of 54 correlations, 2/54 (3.7%) correlations were found to be significant at p< 0.05 level **(TABLE 26**; p. 224**).**

Only the KOOS component (Pain and Function) scores were found to be significantly KOOS (Function) correlated versus Single-Leg Hop for distance (versus Pain: r = -0.29; p< 0.05; n = 46, and versus Function: r = -0.37; p< 0.05; n = 46); suggesting a negligible relationship between KOOS (Pain), and a low (negative) relationship among Single-Leg Hop for distance, respectively **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs at pre-surgery for pre-surgery for knee flexors of the injured-limb.

5.4.3b - The relationship among P-BOMs versus C-BOMs at pre-surgery for knee extensors (injured limb) for pooled PPM and CON rehabilitation groups (n = 46)

A total of 54 correlations were found by using P-BOMs versus C-BOMs evaluated by the knee extensors of the injured limb **(TABLE 27)**. From this total of 54 correlations, 5/54 (9.3%) correlations were found to be significant at p< 0.01 (x3) and p< 0.05 (x2) significance levels **(TABLE 27**; p. 224**)**. Only the KOOS sub-domain/component scores were significantly correlated versus C-BOMs (i.e., Single-Leg Hop for distance, PF, and RFD). For KOOS (Pain) component score was significantly correlated versus Single-Leg Hop for distance on the injured limb (r = -0.29; p< 0.05; n = 46) at pre-surgery (n = 46); suggesting none or negligible correlation **(TABLE 6**; p. 126). The KOOS (Function) component score was significantly correlated with the Single-Leg Hop for distance for the injured leg (r = -0.37; p< 0.05; n = 46); suggesting a slightly higher, but low (negative) correlation between KOOS (Function) versus Single-Leg Hop for distance **(TABLE 6**; p. 126).

The KOOS (Pain) and KOOS (Function) were significantly correlated versus PF of the knee extensors (injured leg), r = -0.42 (p< 0.01) and r = -0.42 (p< 0.01), pre-surgery, respectively; suggesting both KOOS (Pain and Function) are low and negatively correlated to PF. Finally, KOOS (QoL) was significantly correlated versus RFD of the knee extensors (r = -0.42; p< 0.01; n = 46) (injured leg); suggesting a low (negative) relationship **(TABLE 6**; p. 126). No other significant relationships were found among P-BOMs versus C-BOMs at pre-surgery for knee extensors of the injured-limb.

5.4.3c - The relationship among P-BOMs versus C-BOMs at pre-surgery for knee flexors (non-injured limb) for pooled PPM and CON rehabilitation groups (n = 46)

A total of 54 correlations were found, by using P-BOMs versus C-BOMs evaluated by the knee flexors of the non-injured limb **(TABLE 28)**. From this total of 54 correlations, 1/54 correlations were found to be significant at p< 0.05 level **(TABLE 28**; p. 224**)**. Only the IKDC was significantly correlated versus SMP-FE (r = -0.31; p< 0.05; n = 46); suggesting a low (negative) relationship between IKDC and SMP-FE **(TABLE 6**; p. 126). No other significant relationships were found among P-BOMs versus C-BOMs at pre-surgery for knee flexors for the non-injured limb.

5.4.3d - The relationship among P-BOMs versus C-BOMs at pre-surgery for knee extensors (non-injured limb) for pooled PPM and CON rehabilitation groups (n = 46)

A total of 54 correlations were found among P-BOMs and C-BOMs outcome/variables evaluated by the knee extensors of the non-injured limb **(TABLE 33)**. From this total of 54 correlations, 2/54 (3.7%) correlation coefficients were found to be significant (p< 0.05) **(TABLE 29; p. 224).** The KOOS component (Function) score was significantly correlated versus EMD (r = -0.34; p< 0.05; n

= 46); suggesting a low (positive) relationship between KOOS (Function) and EMD **(TABLE 6**; p. 126**)**. Finally, the KOOS component (QoL) score was significantly correlated versus RFD (r = -0.31; p< 0.05; n = 46); suggesting a low (negative) relationship between KOOS (QoL) and EMD **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs for the knee extensors of the non-injured limb.

TABLE 26 - Relationships between the P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery assessment for knee flexors (injured limb) (pooled PPM/CON rehabilitation groups) (n = 46).

		Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
	VAS (pain)	.08 .60	.08 .61	.09 .55	-.13 .38	-.20 .18	-.04 .78
	IKDC	-.16 .28	.25 .10	-.04 .78	.06 .67	.02 .92	-.12 .44
	Lyshom	.11 .47	.15 .33	.19 .21	.14 .35	-.07 .67	-.06 .69
KOOS	(symptoms)	-.07 .64	-.22 .14	-.15 .34	-.26 .08	-.22 .14	-.04 .79
KOOS	(pain)	**-.29† .05**	-.19 .20	-.16 .29	-.22 .14	-.13 .39	-.07 .67
KOOS	(function)	**-.37‡ .01**	-.26 .08	-.20 .19	-.19 .20	-.21 .16	-.10 .50
KOOS	Sport/rec)	-.24 .11	-.21 .16	-.14 .36	-.04 .81	-.26 .08	-.03 .85
KOOS	(QoL)	.02 .89	-.14 .37	-.10 .51	-.09 .53	-.13 .40	-.03 .84
	Performance profile	-.05 .72	-.23 .13	-.15 .33	-.19 .22	.00 .99	.02 .90

TABLE 27 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance (injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee extensors of the injured limb (n = 46).

		Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
	VAS (pain)	.08 .60	.08 .61	.03 .85	.22 .14	.17 .26	.12 .44
	IKDC	-.16 .28	.25 .10	.04 .79	.02 .90	-.01 .92	-.19 .20
	Lyshom	.11 .47	.15 .33	.24 .10	.11 .46	-.20 .19	-.12 .41
KOOS	(symptoms)	-.07 .64	-.22 .14	-.26 .08	.15 .33	-.09 .53	.10 .51
KOOS	(pain)	**-.29† .05**	-.19 .20	**-.42‡ .01**	-.03 .86	-.02 .88	.06 .69
KOOS	(function)	**-.37‡ .01**	-.26 .08	**-.49‡ .001**	-.07 .64	.02 .90	-.01 .96
KOOS	Sport/rec)	-.24 .11	-.21 .16	-.23 .13	-.12 .41	.03 .83	-.06 .69
KOOS	(QoL)	.02 .89	-.14 .37	.01 .93	**-.42‡ .001**	-.15 .32	-.17 .27
	Performance profile	-.05 .72	-.23 .13	.01 .97	-.26 .09	.07 .65	.07 .65

TABLE 28 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance (injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee flexors of the non-injured limb (n = 46).

		Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
	VAS (pain)	-.032 .83	.078 .60	.128 .40	.085 .58	.098 .52	.184 .22
	IKDC	-.22 .14	-.10 .52	-.12 .42	-.15 .33	-.12 .42	**-.31† .04**
	Lyshom	-.06 .68	-.10 .49	-.09 .57	-.18 .24	-.23 .12	.00 .98
KOOS	(symptoms)	-.09 .57	-.07 .64	.00 1.00	-.17 .26	-.02 .91	.05 .75
KOOS	(pain)	-.19 .20	.02 .89	-.16 .29	-.08 .61	.15 .32	.11 .49
KOOS	(function)	-.26 .08	.03 .84	-.14 .36	-.05 .76	.15 .31	.08 .59
KOOS	Sport/rec)	-.21 .17	.11 .45	-.04 .81	.06 .70	-.16 .29	.24 .11
KOOS	(QoL)	-.04 .79	.28 .06	.17 .26	.08 .61	-.10 .52	.06 .70
	Performance profile	-.14 .35	-.04 .80	.08 .58	.15 .33	-.26 .08	.02 .89

TABLE 29 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance (injured), ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery for pooled PPM and CON rehabilitation groups for the knee extensors of the non-injured limb (n = 46).

		Single-leg-hop (distance)	ATFD	PF	RFD	EMD	SMP-FE
	VAS (pain)	-.03 .83	.08 .60	.13 .40	.23 .12	-.06 .71	.07 .62
	IKDC	-.22 .14	-.10 .52	-.12 .42	-.13 .40	-.20 .18	-.22 .14
	Lyshom	-.06 .68	-.10 .49	-.09 .57	-.02 .88	-.08 .59	.13 .38
KOOS	(symptoms)	-.09 .57	-.07 .64	.00 1.00	.10 .52	.25 .10	-.03 .82
KOOS	(pain)	-.19 .20	.02 .89	-.16 .29	-.02 .91	.21 .16	-.11 .45
KOOS	(function)	-.26 .08	.03 .84	-.14 .36	-.17 .25	**.34† .02**	-.20 .19
KOOS	Sport/rec)	-.21 .17	.11 .45	-.04 .81	-.26 .08	.19 .20	-.09 .55
KOOS	(QoL)	-.04 .79	.28 .06	.17 .26	**-.31† .04**	.16 .28	-.02 .90
	Performance profile	-.14 .35	-.04 .80	.08 .58	.16 .30	.05 .75	.00 .97

5.4.4 - The relationship amongst P-BOMs at the acute, intermediate, and late phase of rehabilitation

5.4.4.1 - The relationship among P-BOMs at the acute phase of rehabilitation for PPM rehabilitation group only (n = 23)

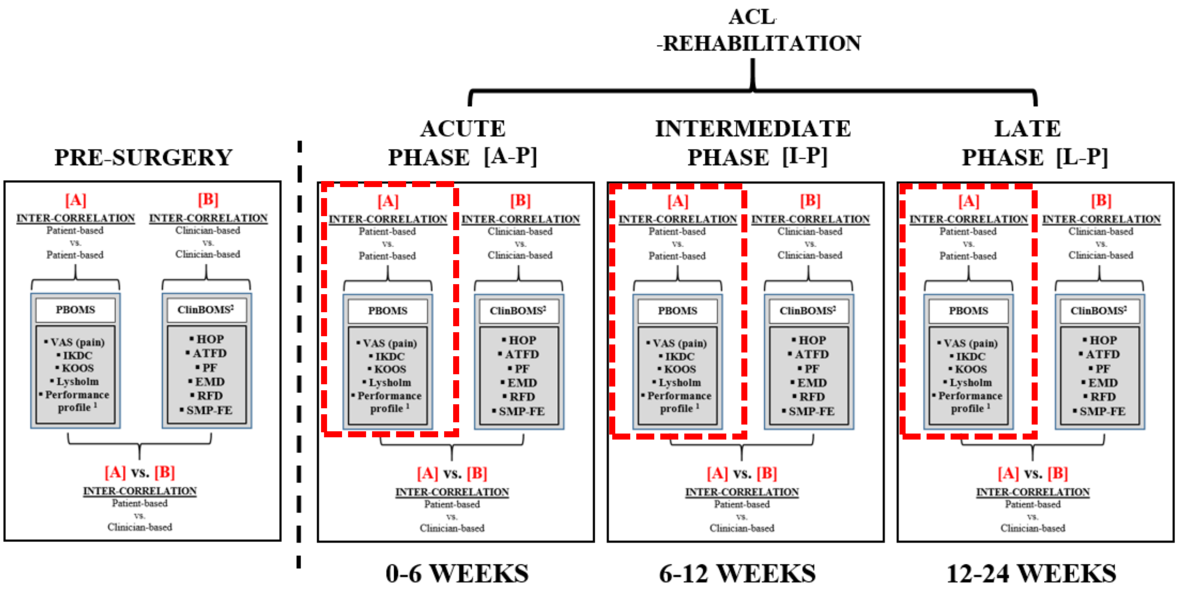

FIGURE 28 - Overview of inter-correlations (P-BOMs) evaluated at acute, intermediate, and late phase of rehabilitation for PPM rehabilitation group only.

The relationships among P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) were evaluated at the acute phase (6 weeks), intermediate phase (6 weeks), and late phase (12-24 weeks) of rehabilitation for the PPM rehabilitation group only (n = 23) **(FIGURE 28)**. The relationships among P-BOMs (IKDC, KOOS, Lysholm, and Performance Profile) were computed at the acute phase of rehabilitation for the PPM rehabilitation group (n = 23). A total of 45 correlation coefficients was found among the inter-correlation of P-BOMs **(TABLE 30**; p. 227**)**. From this total of 45 correlations, 16/45 (35.5%) correlation coefficients were found to be significant at p< 0.01 (x3) and p< 0.05 (x2) significance levels.

For the IKDC, 4 correlation coefficients were found to be significant versus VAS (Pain) (r = -0.71; p< 0.001; n = 23), and versus KOOS component (Pain, Function, and QoL) scores ranging (r) from -0.45 to -0.66 (p< 0.05); suggesting a high (negative) relationship for the IKDC versus the VAS (Pain) **(TABLE 6**; p. 126**)**. Furthermore, for the KOOS component scores versus IKDC [versus Pain: (r = 0.66; p< 0.001; n = 23); versus Function: (r = -0.60; p< 0.001; n = 23); and versus QoL: (r = -0.45; p< 0.05; n = 23)] suggests a low (negative) to moderate (negative) relationships for the IKDC among KOOS component scores **(TABLE 6**; p. 126**)**. For the Lysholm, 2 correlations were found for the IKDC ($r = 0.77$; $p< 0.001$; $n = 23$) and versus VAS (Pain) ($r = -0.55$; $p< 0.01$; $n = 23$); suggesting a high (positive) and moderate (negative) relationships between the Lysholm, respectively **(TABLE 6**; p. 126**)**.

For the VAS (Pain), 2 correlations were found to be significant for the KOOS component (Function: $r = -0.61$; $p< 0.001$; $n = 23$, and Pain: $r = 0.63$; $p< 0.001$; $n = 23$) scores; suggesting a moderate (negative) and moderate (positive) relationships among VAS (Pain) and KOOS component scores **(TABLE 6**; p. 126**)**.

For the inter-correlation among the KOOS component scores, a total of 7 correlation coefficients was found (ranging from [r] 0.45 to 0.86 ($p< 0.05$; $n = 460$); suggesting a wide disparity of correlation coefficients varying from a low to very high (positive) relationships **(TABLE 6**; p. 126**)**. Noticeably, the highest correlation coefficient (representing statistical and clinical relevance, ≤ 0.70) found among the inter-correlation of KOOS component scores was reported for the KOOS (QoL) versus KOOS (Sport/rec) ($r = 0.77$; $p< 0.001$; $n = 46$) and KOOS (Function) versus KOOS (Pain) ($r = 0.86$; $p< 0.001$; $n = 46$); suggesting high (positive) relationships between KOOS (QoL, Sport/rec, Function, and Pain) component scores **(TABLE 6**; p. 126**)**.

In the remaining correlation coefficient found, the Performance Profile (non-injured limb) was significant correlated with the KOOS component (QoL) score ($r = 0.49$; $p< 0.05$; $n = 23$), suggesting a moderate (positive) relationship **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs inter-correlation at the acute phase of rehabilitation for the PPM rehabilitation group.

TABLE 30 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) at acute phase of rehabilitation for the PPM rehabilitation group condition (n = 23).

		VAS (pain)	IKDC	Lysholm	KOOS (symptoms)	KOOS (pain)	KOOS (function)	KOOS (sport/rec)	KOOS (QoL)	Performance profile (injured)	Performance profile (non-injured)
	VAS (pain)	1.00									
	IKDC	-.72 .001									
	Lysholm	-.55 .01	.77 .001	1.00							
KOOS	(symptoms)	.14 .52	-.20 .36	-.23 .30							
KOOS	(pain)	.63 ⋮ .001	-.61 ⋮ .001	-.38 .07	.48 † .02	1.00					
KOOS	(function)	.66 ⋮ .001	-.60 ⋮ .001	-.38 .07	.32 .13	.86 ⋮ .001					
KOOS	(sport/rec)	.09 .69	-.24 .26	-.06 .78	.37 .08	.50 ‡ .01	.45 † .03	1.00			
KOOS	(QoL)	.30 .17	-.45 † .03	-.17 .43	.24 .28	.49 † .02	.49 † .02	.77 ⋮ .001			
Performance profile	(injured)	.11 .62	-.01 .96	.02 .94	-.05 .80	.19 .39	.25 .25	-.06 .79	(Ctrl) .56	1.00	
Performance profile	(non-injured)	.15 .49	-.02 .92	.19 .38	-.01 .96	.00 .99	.28 .20	.19 .37	.49 † .02	.03 .88	1.00

5.4.4.2 - The relationship among P-BOMs at the intermediate phase of rehabilitation for PPM rehabilitation group only (n = 23)

The relationships among P-BOMs (IKDC, KOOS, Lysholm, and Performance Profile) were computed at the intermediate phase of rehabilitation (12 weeks post-ACLR surgery) for the PPM rehabilitation group (n =23). A total of 45 correlations were found while evaluating inter-correlations of P-BOMs. From this total of 45 correlations, 12/45 (27%) correlations were found to be significant at p< 0.05 (x3), p< 0.01 (x2), and p< 0.001 (x9) significance levels **(TABLE 31)**.

For the IKDC, 4 correlation coefficients were found among KOOS component (Pain, Function, Sport/rec, and QoL) scores ranging (r) from -0.56 to -0.80 (p< 0.01 - 0.001; n = 92). More specifically, IKDC versus KOOS [versus Function: (r = 0.67; p< 0.001; n = 23); versus Pain: (r = -0.60; p< 0.001; n = 23); versus QoL: (r = -0.80; p< 0.001; n = 23); and versus QoL: (r = -0.56; p< 0.01; n = 23)]; suggests moderate (negative) to high (negative) relationships for the IKDC among KOOS component scores **(TABLE 6**; p. 126**)**.

TABLE 31 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) at intermediate phase of rehabilitation for the PPM rehabilitation group condition[91].

		VAS (pain)	IKDC	Lysholm	KOOS (symptoms)	KOOS (pain)	KOOS (function)	KOOS (sport/rec)	KOOS (QoL)	Performance profile (injured)	Performance profile (non-injured)
	VAS (pain)	[redacted]									
	IKDC	-.20 .35	[redacted]								
	Lysholm	-.49 † .02	.65 ⁝ .001	[redacted]							
KOOS	(symptoms)	.30 .17	-.16 .48	-.52 ‡ .01	[redacted]						
	(pain)	.38 .07	.60 ⁝ .001	.61 ⁝ .001	.37 .09	[redacted]					
	(function)	.37 .08	-.67 ⁝ .001	-.83 ⁝ .001	.75 ⁝ .001	.60 ⁝ .001	[redacted]				
	(sport/rec)	.07 .75	-.56 ‡ .01	-.32 .14	-.13 .55	.39 .06	.16 .46	[redacted]			
	(QoL)	-.03 .90	-.80 ⁝ .001	-.42 † .05	.03 .90	.47 † .02	.40 .06	.60 ⁝ .001	[redacted]		
Performance profile	(injured)	-.17 .44	.12 .58	.29 .19	-.41 .05	-.19 .39	-.32 .13	.11 .62	.12 .59	[redacted]	
	(non-injured)	.22 .32	.07 .73	.08 .71	-.08 .71	.06 .78	-.13 .54	-.29 .18	-.11 .60	-.01 .97	[redacted]

For the inter-correlation among the KOOS component scores, a total of 2 correlation coefficients was found ranging from [r] 0.60 to 0.75 ($p < 0.01$; n = 46). More specifically, KOOS (Function) versus KOOS (Pain) (r = 0.60; $p < 0.001$; n = 23), and KOOS (Function) versus KOOS (Symptoms) (r = 0.75; $p < 0.001$; n = 23) suggests a moderate (positive) to a high (positive) relationships for the KOOS component scores **(TABLE 6**; p. 126**)**.

For the Lysholm, 2 correlations were found for the IKDC (r = 0.65; $p < 0.001$; n = 23) and versus VAS (Pain) (r = -0.49; $p < 0.01$; n = 23); suggesting a low (positive) and a moderate (positive) relationships between the Lysholm, respectively **(TABLE 6**; p. 126**)**.

Similarly, in the remaining 4 correlations, the Lysholm was significantly correlated with the KOOS component (Symptoms, Pain, Function, and QoL) scores ranging (r) from -0.42 to -0.83 ($p < 0.05$ - 0.001; n = 92). More specifically, Lysholm versus KOOS [versus Symptoms: (r = -0.52; $p < 0.01$; n = 23); versus Pain: (r = -0.61; $p < 0.001$; n = 23); versus Function: (r = -0.83; $p < 0.001$; n =

[91] The top number in each matrix block refers to correlation coefficient value computed for each inter-correlation (i.e., r = 0.56), and the number below is the statistical significance value reported for this interaction (i.e., $p < 0.01$). For ease of interpretation all statistically significant correlation coefficients have been highlighted in bold and the following have been used († significant correlation at $p < 0.05$; ‡ significant correlation at $p < 0.01$; and ⁝ significant correlation at $p < 0.001$ significance levels).

23); and versus QoL: ($r = -0.42$; $p < 0.05$; $n = 23$)]; suggests low (negative) to high (negative) relationships for the Lysholm among KOOS component scores **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs at the intermediate phase of rehabilitation.

5.4.4.3 - The relationship among P-BOMs at the late phase of rehabilitation for PPM rehabilitation group only (n = 23)

The relationships among P-BOMs (IKDC, KOOS, Lysholm, and Performance Profile) were computed at the late phase of rehabilitation (24 weeks post-surgery) for the PPM rehabilitation group condition ($n = 23$). A total of 45 correlations were found while evaluating inter-correlations of P-BOMs (as above). From this total of 45 correlations, 27/45 (50%) correlations were found to be significant at $p < 0.05$ (x3), $p < 0.01$ (x4), and $p < 0.001$ (x20) significance levels **(TABLE 32)**.

For the IKDC, one correlation coefficient was found for the VAS (Pain) ($r = -0.81$; $p < 0.001$; $n = 23$) and 3 correlation coefficients were found for the IKDC versus KOOS component Pain, Function, Sport/rec, and QoL) score ranging from ($r =$) -0.65 to -0.91 ($p < 0.001$; $n = 69$). More specifically, IKDC versus KOOS [versus Function: ($r = -0.65$; $p < 0.001$; $n = 23$); versus Pain: ($r = -0.83$; $p < 0.001$; $n = 23$); versus QoL: ($r = -0.91$; $p < 0.001$; $n = 23$); and versus Sport/rec: ($r = -0.80$; $p < 0.01$; $n = 23$)] suggests a moderate (negative) to high (negative) relationships for the IKDC among KOOS component scores **(TABLE 6**; p. 126**)**.

For the Lysholm, 2 correlation coefficients were found for the IKDC ($r = 0.86$; $p < 0.001$; $n = 23$) and versus VAS (Pain) ($r = -0.59$; $p < 0.001$; $n = 23$); suggesting high (positive) and moderate (negative) relationships for the Lysholm, respectively **(TABLE 6**; p. 126**)**. In the latter, the Lysholm versus VAS (Pain) suggested a moderate (negative) correlation. In the remaining 5 correlations, the Lysholm was significantly correlated to the KOOS component (Pain, Function, Symptoms, Sport/rec, and QoL) score ranging from ($r =$) -0.66 to -0.90 ($p < 0.001$; $n = 115$). More specifically, Lysholm versus KOOS [versus Symptoms: ($r = -0.66$; $p < 0.001$; $n = 23$); versus Pain: ($r = -0.90$; $p < 0.001$; $n = 23$); versus Function: ($r = -0.88$; $p < 0.001$; $n = 23$); versus Sport/rec: ($r = -0.88$; $p < 0.001$; $n = 23$)], and versus QoL ($r = -0.68$; $p < 0.001$; $n = 23$) suggest moderate (negative) to high (negative) relationships for the IKDC among KOOS component scores **(TABLE 6**; p. 126**)**.

TABLE 32 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) at late phase of rehabilitation for the PPM rehabilitation group condition (n = 23)[92].

	VAS (pain)	IKDC	Lysholm	KOOS (symptoms)	KOOS (pain)	KOOS (function)	KOOS (sport/rec)	KOOS (QoL)	Performance profile (injured)	Performance profile (non-injured)
VAS (pain)										
IKDC	-.81 ⁞ .001									
Lysholm	-.59 ⁞ .001	.86 ⁞ .001								
KOOS (symptoms)	.06 .80	-.37 .08	-.66 ⁞ .001							
KOOS (pain)	.42 † .05	-.83 ⁞ .001	-.90 ⁞ .001	.52 ‡ .01						
KOOS (function)	.20 .35	-.65 ⁞ .001	-.88 ⁞ .001	.71 ⁞ .001	.88 ⁞ .001					
KOOS (sport/rec)	.48 † .02	-.80 ⁞ .001	-.88 ⁞ .001	.57 ⁞ .001	.83 ⁞ .001	.80 ⁞ .001				
KOOS (QoL)	.96 ⁞ .001	-.91 ⁞ .001	-.68 ⁞ .001	.13 .57	-.58 ‡ .01	.33 .13	.62 ⁞ .001			
Performance profile (injured)	-.40 .11	.24 .34	.45 .07	-.42 .09	-.31 .22	-.37 .15	-.26 .30	.01 .97		
Performance profile (non-injured)	-.11 .68	.30 .23	.61 ‡ .01	-.58 ‡ .01	-.48 .05	-.52 † .03	-.46 .07	-.14 .59	.62 .01	

For the inter-correlation among the KOOS component scores, a total of 8 correlation coefficients was found ranging from [r] 0.53 to 0.88 ($p < 0.01$- 0.001; n = 184). Noticeably, the highest correlation coefficient (representing statistical and clinical relevance, ≤ 0.70) found among the inter-correlation of KOOS component scores was reported for the KOOS (Function) versus KOOS (Symptoms) (r = 0.71; $p < 0.001$; n = 23), KOOS (Function) versus KOOS (Pain) (r = 0.88; $p < 0.001$; n = 23), KOOS (Sport/rec) versus KOOS (Function) (r = 0.80; $p < 0.001$; n = 23), and KOOS (Sport/rec) versus KOOS (Pain) (r = 0.83; $p < 0.001$; n = 23) suggest high (positive) relationships between KOOS component scores **(TABLE 6**; p. 126**)**.

In the remaining correlation coefficients found, the Performance Profile (non-injured limb) was significantly correlated with the KOOS component (Symptoms: r = -0.59; $p < 0.01$; n = 23; Function: r = -0.52; $p < 0.05$; n = 23) scores; suggesting moderate (negative) relationships between Performance Profile (non-injured limb) among KOOS component scores **(TABLE 6**; p. 126**)**. Similarly, the Performance Profile (non-injured limb) was significantly correlated with the Lysholm

[92] The top number in each matrix block refers to correlation coefficient value computed for each inter-correlation (i.e., r = 0.56), and the number below is the statistical significance value reported that this interaction (i.e., $p < 0.01$). For ease of interpretation all statistically significant correlation coefficients have been highlighted in bold and the following have been used († significant correlation at $p < 0.05$; ‡ significant correlation at $p < 0.01$; and ⁞ significant correlation at $p < 0.001$ significance levels).

(r = 0.61; p< 0.01; n = 23) and versus Performance Profile (injured limb) (r = 0.62; p< 0.01; n = 23); suggesting moderate (positive) relationships between the Performance Profile, respectively **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs at the late phase of rehabilitation.

5.4.4.4 - Summary section evaluating the relationships among P-BOMs found for PPM rehabilitation group at the acute, intermediate, and late phases of rehabilitation compared to CON rehabilitation group

For the CON versus PPM rehabilitation group, a dissimilar proportion of significant correlations (p< 0.05) were found (CON: 38.4% versus PPM: 55.6%) at pre-surgery (6/28 versus 18/28), acute (10/28 versus 15/28), intermediate (7/28 versus 12/28), and late phases (20/28 versus 27/28) of rehabilitation, respectively. On further inspection of the range of correlation coefficients found at pre-surgery (r = 0.58 to 0.91 versus 0.29 to 0.59 [-0.41 to -0.60]), acute phase (r = 0.44 to 0.67 [-0.44 to -0.56] versus 0.44 to 0.96 [-0.45 to -0.71]), intermediate phase (r = 0.60 to 0.68 [-0.41 to -0.59] versus 0.60 to 0.74 [-0.42 to -0.83]), and late phase (r = 0.46 to 0.90 [-0.53 to -0.71] versus 0.42 to 0.62 [-0.52 to -0.92]) of rehabilitation, respectively, with similar magnitudes of correlation coefficients found.

In relation to the interpretation of correlation coefficients (statistical/clinical relevance [r ≥ 0.70]), suggested by 'high' or 'very high' (categories) (see Hinkle et al., 2003), for respective PPM (20/112) and CON rehabilitation group (13/112) conditions, suggested that a small percentage of significant correlations (p< 0.05) fulfilling criterion were found between the PPM (17.6%) and CON rehabilitation groups (11.6%). It is noteworthy, that the highest proportions of these significant correlation coefficients (at r ≥ 0.70) were found within the late phases of rehabilitation with the PPM and CON rehabilitation groups reporting 12/13 (92.3%) and 12/20 (60%), respectively. The remaining 8/112 (7.1%) of significant correlation coefficients fulfilling statistical/clinical relevance (r ≥ 0.70) were found infrequently and sporadically within acute and intermediate phases of rehabilitation **(TABLE 33).**

With regards to the computed inter-correlations of P-BOMs (r≥ 0.70[93]), PPM and CON rehabilitation groups were found reporting similar strength of correlations, and predominately statistical significant/relevant correlations were found within the late phases of rehabilitation for PPM and CON rehabilitation groups. For example, within the late phase of rehabilitation for the CON rehabilitation group condition, only a small proportion (13/112) of correlation coefficients were found between IKDC versus VAS (Pain) [r = -0.81; p< 0.001; n = 23] and versus KOOS (Pain,

[93] Cut-off values are based on suggestions of previous literature (see Nunnally, 1978).

Sport/rec, and QoL) [ranging from (r) -0.81 to 0.91 ($p< 0.001$; n = 96), Lysholm versus IKDC [r = 0.86; $p< 0.001$; n = 23], and versus KOOS (Pain, Function, and QoL [ranging from (r) -0.81 to 0.90; $p< 0.001$; n = 69]), VAS (Pain) versus KOOS (QoL) [r = -0.96; $p< 0.001$; n = 23], and inter-correlation among the KOOS component (Function versus symptoms; Sport/rec versus Function; Sport/rec versus Pain; and Function versus Pain) scores ranging from (r) 0.71 to 0.88 ($p< 0.001$; n = 69).

Similarly, for the PPM rehabilitation group, a parallel magnitude of correlation coefficients were found within some of the same P-BOMs (IKDC versus KOOS component (Pain, Function, Sport/rec, and QoL) [ranging from (r) -0.81 to 0.91 ($p< 0.001$; n = 23)] scores, Lysholm versus IKDC [r = 0.78; $p< 0.001$; n=69] and versus KOOS component (Pain, Function, and QoL) [ranging from (r) -0.71 to 0.85 ($p< 0.001$; n = 23)] scores, and finally inter-correlation among the KOOS component (Pain And Function) scores ranging from (r) 0.74 to 0.90 ($p< 0.001$; n = 92)] scores at the late phase of rehabilitation.

With the remaining correlation coefficients found at the acute [(IKDC versus Lysholm (r = 0.77; $p< 0.001$, n = 23), and versus VAS (Pain) (r = -0.71; $p< 0.001$, n = 23); KOOS (QoL) versus KOOS (Sport/rec) (r = 0.77; $p< 0.001$, n = 23), and versus VAS (Pain) (r = 0.96; $p< 0.001$, n = 23)], and at the intermediate phase [(Lysholm versus KOOS (Function) (r = -0.83; $p< 0.001$, n = 23); IKDC versus KOOS (QoL) (r = -0.80; $p< 0.001$, n = 23); and KOOS (Function) versus KOOS (Symptoms): r = 0.75; $p< 0.001$, n = 23] of the PPM rehabilitation group (excluding only one significant correlation found at pre-surgery for the CON rehabilitation group [KOOS (Pain) versus KOOS (Function): r = 0.91; $p< 0.001$, n = 23] were similar in strength of correlations.

TABLE 33 - Inter-correlation among P-BOMs (VAS [Pain], IKDC, KOOS, and Performance Profile) [total number of significant correlations found/the maximum number] [see Hinkle et al., 2003] for either a positive or negative relationship (alongside with minimum to maximum ranges] of correlation coefficients found at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation groups (n = 23), respectively.

	PRE-SURGERY			ACUTE PHASE (0-6 WEEKS)			INTERMEDIATE PHASE (6-12 WEEKS)			LATE PHASE (12-24 WEEKS)		
Inter-correlation amongst patient-based outcomes (experimental)	<u>**RANGE**</u>: **0.29 to 0.59** (10/28) **[-0.41 to -0.60]** (8/28)			<u>**RANGE**</u>: **0.45 to 0.96** (n=5/28) **[-0.45 to -0.71]** (10/28)			<u>**RANGE**</u>: **0.60 to 0.74** (3/28) **[-0.42 to -0.83]** (9/28)			<u>**RANGE**</u>: **0.42 to 0.62** (8/28) **[-0.52 to -0.92]** (19/28)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			Very high:	**1**		Very high:			Very high:		**3**
	High:			High:	**3**		High:	**1**	**2**	High:		**10**
	Moderate:	6	3	Moderate:	3	3	Moderate:	2	5	Moderate:	6	6
	Low:	1	7	Low:	4	1	Low:		2	Low:	2	
	Negligible:	1		Negligible:			Negligible:			Negligible:		
Inter-correlation amongst patient-based outcomes (control)	<u>**RANGE**</u>: **0.58 to 0.91** (6/28)			<u>**RANGE**</u>: **0.44 to 0.67** (3/28) **[-0.44 to -0.56]** (7/28)			<u>**RANGE**</u>: **0.60 to 0.68** (2/28) **[-0.41 to -0.59]** (5/28)			<u>**RANGE**</u>: **0.46 to 0.90** (17/28) **[-0.53 to -0.71]** (3/28)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:	**1**		Very high:			Very high:			Very high:	**1**	
	High:			High:			High:			High:	**10**	**1**
	Moderate:	5		Moderate:	2	4	Moderate:	2	2	Moderate:	5	2
	Low:			Low:		4	Low:		3	Low:	1	
	Negligible:			Negligible:			Negligible:			Negligible:		

5.5 - The relationship among C-BOMs at the acute, intermediate, and late phases of rehabilitation for PPM and CON rehabilitation groups

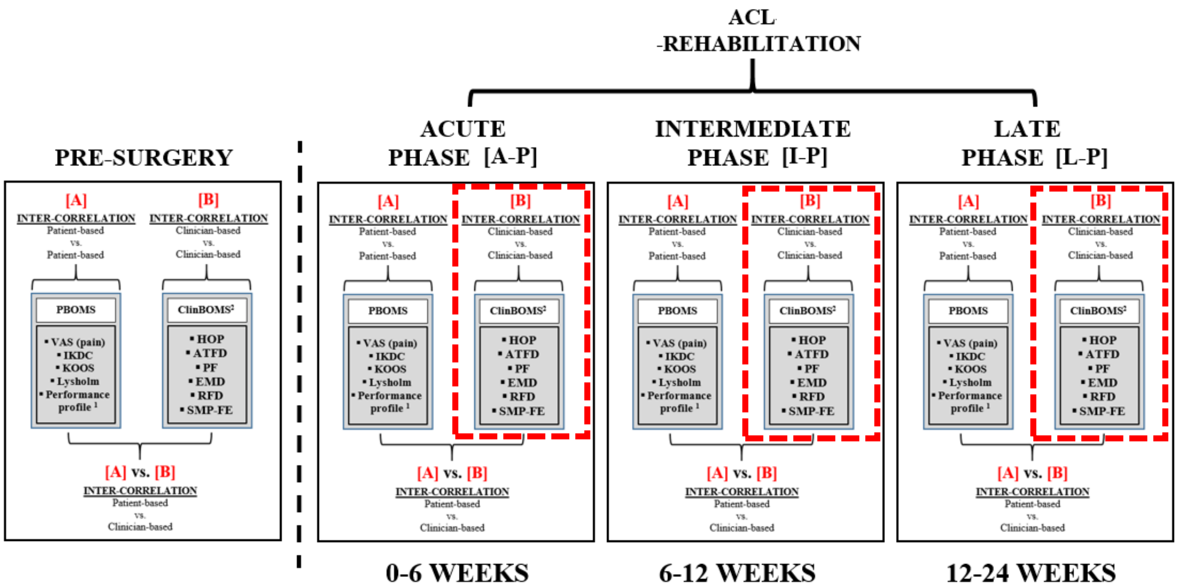

FIGURE 29 - Overview of inter-correlations (C-BOMs) evaluated at acute, intermediate, and late phase of rehabilitation for PPM and CON rehabilitation groups (n = 23), respectively.

The relationship among C-BOMs (Single-Leg Hop for distance [where clinically appropriate], ATFD, PF, EMD, RFD, and SMP-FE) were computed at the acute (0-6 weeks), intermediate (6-12 weeks), and late phase (12-24 weeks) of rehabilitation for the knee flexors and knee extensors for PPM (n = 23) and CON rehabilitation groups (n = 23) **(FIGURE 29)**.

The Single-Leg Hop for distance is contraindicated for a recent ACLR knee (see p. 189) and is, thus, not available for analysis at the acute phase of rehabilitation (i.e., 6 weeks post-surgery). It is noteworthy, that the Single-Leg Hop for distance (non-injured limb) was additionally evaluated at this acute phase of rehabilitation. One relationship was found within this phase for the non-injured limb versus PF[94] assessed by the knee extensors suggesting a low (positive) relationship between PF and Single-Leg Hop for distance ($r = 0.46$; $p< 0.05$; $n = 23$) **(TABLE 6**; p. 126**)**. No other significant relationships were found for the Single-Leg Hop for distance for the non-injured leg versus the knee flexors/extensors associated with the injured and non-injured limbs at the acute phase of rehabilitation. Moreover, within the intermediate and late phases of rehabilitation, significant correlations between

[94] Peak Force (PF).

the Single-Leg Hop for distance were infrequently reported and sporadically found within the intermediate and late phases of rehabilitation, with no relationships found for the Single-Leg Hop for distance (non-injured leg) versus any other C-BOMs.

In addition to, the outcome of the inter-correlations computed at acute, intermediate and late phases of rehabilitation for all clinician-based outcome (as above) resulted in only 53/440 (12%) of correlation coefficients found to be significant ($p < 0.05$) (CON: 24/220; PPM: 29/220). Due to the infrequent and sporadic relationships found with C-BOMs, and combined with only two of these correlation coefficients reporting statistical and clinical relevance (discussed below), it was not deemed necessary to discuss each inter-correlation computed for the injured and non-injured limbs associated with the knee flexors and knee extensor at each phase of rehabilitation, separately. Subsequently, it was more appropriate to discuss the outcome of knee flexors and knee extensors of the injured and non-injured limbs separately for the acute, intermediate, and late phases of rehabilitation for PPM and CON rehabilitation groups (see below).

5.5.1 - Knee flexors and extensors of the injured limb at pre-surgery, and at acute, intermediate, and late phases of rehabilitation for PPM and CON rehabilitation groups

For the CON versus PPM rehabilitation groups for the injured limbs at pre-surgery (0/15 versus 0/15), and at the acute (1/10 versus 1/10), intermediate (1/15 versus 2/15), and late phases (1/15 versus 2/15) of rehabilitation indicated a similar proportions of significant correlations ($p < 0.05$) for the knee flexors (CON: 5.5%; PPM: 12.7%), respectively **(see TABLE 34** and **TABLE 35)**, respectively**)**. For the knee extensors of the injured-limb across the same pre-surgery (1/15 versus 0/15), acute (0/10 versus 2/10), intermediate (4/15 versus 0/15), and late (2/15 versus 3/15) phases of rehabilitation, similar proportions of significant correlations ($p < 0.05$) for the CON and PPM rehabilitation groups were found, 12.7% and 9%, respectively.

For the knee flexors and extensors for the injured limb for both PPM and CON rehabilitation groups across pre-surgery, acute, intermediate, and late phases of rehabilitation, a comparable magnitude of correlation coefficients were observed. However, in relation to the interpretation of correlation coefficients that may indicate statistical significant ($r \geq 0.70$), and suggested by a correlation coefficient within a 'high' or 'very high' (categories) (see Hinkle et al., 2003) for the knee flexors and extensors (injured-limb) of the respective PPM and CON rehabilitation groups. Only one correlation coefficient was reported to be fulfilling this criterion at the late phase of rehabilitation for the knee flexors (injured limb) in the PPM rehabilitation group condition between EMD versus PF ($r = 0.83$ ($p < 0.001$; $n = 23$); suggesting a high (positive) relationship between EMD and PF **(TABLE 6**; p. 126). No other statistical/clinically relevant ($r \geq 0.70$) relationships were found among all C-BOMs at pre-surgery, and at the acute, intermediate and late phases of rehabilitation for knee flexors and extensors as evaluated by the PPM and CON rehabilitation groups for the injured limb.

TABLE 34 - Inter-correlation among C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group condition (n = 23) for the knee flexors (injured limb).

		PRE-SURGERY		**ACUTE PHASE** (0-6 WEEKS)		**INTERMEDIATE PHASE** (6-12 WEEKS)		**LATE PHASE** (12-24 WEEKS)	
Inter-correlation amongst clinician-based outcomes (experimental)	**RANGE:**	**0.39 to 0.43** (2/15)		**0.52** (1/10)		**0.42** (1/15) **[-0.60]** (1/15)		**0.53 to 0.83** (2/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:							**1**	
	Moderate:			1			1	1	
	Low:	2				1			
	Negligible:								
Inter-correlation amongst clinician-based outcomes (control)	**RANGE:**			**[-0.47]** (1/10)		**[-0.61]** (1/15)		**0.48** (1/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:	**NR**				1			
	Low:				1			1	
	Negligible:								

TABLE 35 - Inter-correlation among C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group condition (n = 23) for the knee extensors (injured limb).

		PRE-SURGERY		ACUTE PHASE (0-6 WEEKS)		INTERMEDIATE PHASE (6-12 WEEKS)		LATE PHASE (12-24 WEEKS)	
Inter-correlation amongst clinician-based outcomes (experimental)	**RANGE:**			**0.41 to 0.58** (2/10)				**0.48 to 0.64** (3/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:	**NR**		1		**NR**		2	
	Low:			1				1	
	Negligible:								
Inter-correlation amongst clinician-based outcomes (control)	**RANGE:**	**0.57** (1/15)				**0.50 to 0.58** (3/15) **[-0.51]** (1/15)		**0.50 to 0.60** (2/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:	1		**NR**		3	1	2	
	Low:								
	Negligible:								

5.5.2 - Knee flexors and extensors of the non-injured limb at pre-surgery, and at acute, intermediate, and late phases of rehabilitation for PPM and CON rehabilitation groups

For the CON versus PPM rehabilitation groups, for the non-injured limbs at pre-surgery (2/15 versus 0/15), and at the acute (1/10 versus 3/10), intermediate (2/15 versus 0/15), and late phases (2/15 versus 3/15) of rehabilitation similar proportions of significant correlations ($p < 0.05$) were indicated for the knee flexors (CON: 12.7%; PPM: 10%), respectively **(**see **TABLE 36** and **TABLE 37**, respectively**)**.

For the knee extensors of the non-injured-limb across the same pre-surgery (3/15 versus 4/15), acute (0/10 versus 3/10), intermediate (2/15 versus 1/15), and late (2/15 versus 3/15) phases of rehabilitation, similar proportions of significant correlations ($p < 0.05$) for the CON and PPM rehabilitation groups were found, 12% and 12%, respectively.

For the knee flexors and extensors for the non-injured limb for both PPM and CON rehabilitation groups across pre-surgery, acute, intermediate, and late phases of rehabilitation, a comparable magnitude of correlations coefficients were observed. However, in relation to the interpretation of correlation coefficients that may indicate statistically significant ($r \geq 0.70$), and suggested by correlation coefficient within a ‘high’ or ‘very high’ (categories) (Hinkle et al., 2003) for the knee flexors and extensors (non-injured limb) of the respective PPM and CON rehabilitation groups. Only one correlation coefficient was reported to be fulfilling this criterion at the late phase of rehabilitation for the knee flexors (non-injured limb) in the PPM rehabilitation group condition between EMD versus PF ($r = 0.71$ ($p < 0.001$; $n = 23$); suggesting a high (positive) relationship between EMD and PF **(TABLE 6**; p. 126**)**.

No other statistical/clinically relevant ($r \geq 0.70$) relationships were found among all C-BOMs at pre-surgery, and at the acute, intermediate and late phases of rehabilitation for knee flexors and extensors as evaluated by the PPM and CON rehabilitation groups for the non-injured limb.

TABLE 36 - Inter-correlation among C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group condition (n = 23) for the knee flexors (non-injured limb).

		PRE-SURGERY		ACUTE PHASE (0-6 WEEKS)		INTERMEDIATE PHASE (6-12 WEEKS)		LATE PHASE (12-24 WEEKS)	
Inter-correlation amongst clinician-based outcomes (experimental)	**RANGE:**			**0.46 to 0.50** (2/10) **[-0.49]** (1/10)				**0.43 to 0.58** (2/15) **[-0.48]** (1/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:	NR		1		NR		1	
	Low:			1	1			1	1
	Negligible:								
Inter-correlation amongst clinician-based outcomes (control)	**RANGE:**	**0.42 to 0.67** (2/15)		**[-0.48]** (1/10)		**0.56** (1/15) **[-0.68]** (1/15)		**0.41** (1/15) **[-0.47]** (1/15)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:	1				1	1		
	Low:	1			1			1	1
	Negligible:								

TABLE 37 - Inter-correlation among C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group condition (n = 23) for the knee extensors (non-injured limb).

	PRE-SURGERY			ACUTE PHASE (0-6 WEEKS)			INTERMEDIATE PHASE (6-12 WEEKS)			LATE PHASE (12-24 WEEKS)		
Inter-correlation amongst clinician-based outcomes (experimental)	**RANGE:** **0.44 to 0.54** (3/15) **[-0.43]** (1/15)			**RANGE:** **0.52** (1/10) **[-0.46 to -0.52]** (2/10)			**RANGE:** **[-0.61]** (1/15)			**RANGE:** **0.43 to 0.71** (3/15)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**		
	High:			**High:**			**High:**			**High:**	**1**	
	Moderate:			Moderate:	1	1	Moderate:		1	Moderate:	1	
	Low:	3	1	Low:		1	Low:			Low:	1	
	Negligible:			Negligible:			Negligible:			Negligible:		
Inter-correlation amongst clinician-based outcomes (control)	**RANGE:** **0.43 to 0.47** (3/15)			**RANGE:**			**RANGE:** **0.54** (1/15) **[-0.57]** (1/15)			**RANGE:** **0.48 to 0.49** (2/15)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**		
	High:			**High:**			**High:**			**High:**		
	Moderate:			Moderate:	**NR**		Moderate:	1	1	Moderate:		
	Low:	3		Low:			Low:			Low:	2	
	Negligible:			Negligible:			Negligible:			Negligible:		

5.6 - The relationships among P-BOMs and C-BOMs at the acute, intermediate, and late phase of rehabilitation

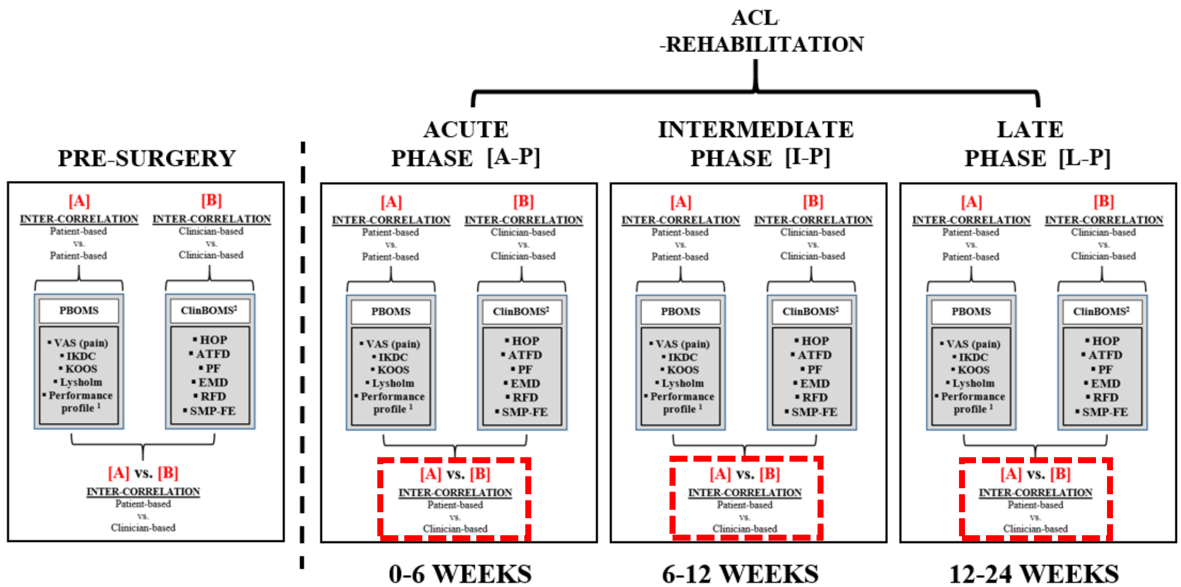

FIGURE 30 - Overview of inter-correlations (P-BOMs versus C-BOMs) evaluated at acute, intermediate, and late phase of rehabilitation for PPM and CON rehabilitation groups (n = 23), respectively.

The relationship among P-BOMs (IKDC, KOOS, Lysholm, and Performance Profile) versus C-BOMs (Single-Leg Hop for distance, ATFD, PF, EMD, RFD, and SMP-FE) were computed at the acute (0-6 weeks), intermediate (6-12 weeks), and late phase (12-24 weeks) of rehabilitation for the knee flexors and knee extensors for CON (n = 23) and PPM rehabilitation groups (n = 23) **(**see **FIGURE 30)**. A total of 54 correlations were found while evaluating inter-correlations of P-BOMs versus C-BOMs/variables (as above) for the knee flexors and extensors for PPM (n = 23) and CON rehabilitation group condition (n = 23) at each phase (i.e., acute, intermediate, and late phases) of rehabilitation for injured and non-injured limbs.

5.6.1. - The relationships among P-BOMs and C-BOMs at the acute phase of rehabilitation

5.6.1a - The relationship among P-BOMs and C-BOMs at acute phase of rehabilitation for knee flexors (injured limb) for PPM rehabilitation group only (n = 23)

A total of 45 correlations were found evaluating P-BOMs versus C-BOMs associated with the knee flexors of the injured limb. From this total of 45 correlations, 5/45 (11%) correlation coefficients were found to be significant at $p < 0.05$ (x3), $p < 0.01$ (x1), and $p < 0.001$ (x1) significance levels. Only the KOOS component (Pain, Function, Symptoms, And Sport/recreation) scores were significantly correlated versus C-BOMs (ATFD, PF, and SMP-FE) at this phase of rehabilitation. The KOOS component (Pain, Symptoms, And Function) scores were significantly correlated with PF (versus Pain: r = -0.64; $p < 0.001$; n = 23; versus Symptoms: r = -0.50; $p < 0.01$; n = 23; and versus Sport/rec: r = -0.44; $p < 0.05$; n = 23), respectively; suggesting a low (negative) relationship between KOOS component (Sport/rec) scores with PF, and moderate (negative) relationships between KOOS component (Symptoms and Pain) scores between PF.

Similarly, KOOS (Pain and Function) were significantly correlated versus ATFD (r = 0.46; $p < 0.05$; n = 23), and versus SMP-FE (r = 0.44; $p < 0.05$; n = 23), respectively; suggesting low (positive) relationships between KOOS component (Pain) score with ATFD, and KOOS component (Function) score with SMP-FE. No other significant relationships were found among P-BOMs versus any C-BOMs at the acute phase of rehabilitation for knee flexors of the injured-limb for the experiment group condition.

5.6.1b - The relationship among P-BOMs versus C-BOMs at the acute phase of rehabilitation for knee extensors (injured limb) for PPM rehabilitation group only (n = 23)

A total of 45 correlations were found while evaluating P-BOMs versus C-BOMs as evaluated by the knee extensors of the injured limb. From this total of 45 correlations, 6/45 (13.3%) correlation coefficients were found to be significant at $p < 0.05$ (x6) level. The VAS (Pain) was significantly correlated with PF (r = -0.45; $p < 0.05$; n = 23), and versus EMD (r = 0.42; $p < 0.05$; n = 23); suggesting that VAS (Pain) is moderately (positively) correlated with PF, and a moderately (negative) correlated with EMD **(TABLE 6**; p. 126**)**. The KOOS component (Pain, Symptoms, And Sport/rec) score was significantly correlated with PF (versus Pain: r = -0.64; $p < 0.001$; n = 23; versus symptoms: r = -0.50; $p < 0.01$; n = 23; and versus Sport/rec: r = -0.44; $p < 0.05$; n = 23), respectively; suggesting a low (negative) relationship between KOOS (Sport/rec) with PF, and moderate (negative) relationships among the KOOS component (Symptoms and Pain) scores between PF **(TABLE 6**; p. 126**)**. Moreover, KOOS component (Function and QoL) scores was significantly correlated with RFD (r = 0.42 to 0.43; $p < 0.05$; n = 46), and similarly KOOS component (Function) score was significantly correlated with ATFD (r = 0.46; $p < 0.05$; n = 23); suggesting low (positive) relationships among ATFD and RFD among all KOOS component scores (as above) **(TABLE 6**; p. 126**)**.

In the remaining correlation coefficient, the Performance Profile (injured limb) was significantly correlated with SMP-FE (r = 0.42; $p < 0.05$; n = 23); suggesting a low (positive) relationship between Performance Profile and SMP-FE **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus any C-BOMs at the acute phase of rehabilitation for knee extensors of the injured-limb for the experiment group condition.

5.6.1c - The relationship between P-BOMs and C-BOMs at the acute phase of rehabilitation for knee flexors (non-injured limb) for the PPM rehabilitation group only (n = 23)

A total of 45 correlations were found while evaluating P-BOMs versus C-BOMs (as above) as evaluated by the knee flexors of the non-injured limb. From this total of 45 correlations, 3/45 (6.6%) correlation coefficients were found to be significant at $p < -0.05$ (x3) level. The KOOS component (symptoms and QoL) score was significantly correlated with PF (versus symptoms: $r = -0.42$; $p < 0.05$; $n = 23$), and RFD (versus QoL $r = 0.46$; $p < 0.05$; $n = 23$); suggesting a low (negative) relationship between KOOS component (Symptoms) score with PF, and a low (positive) relationships between KOOS component (QoL) score with RFD **(TABLE 6**; p. 126**)**. In the latter, RFD was significantly correlated with the Performance Profile (non-injured limb) ($r = -0.46$; $p < 0.05$; $n = 23$); suggesting a low (negative) relationship between the Performance Profile (non-injured limb) with RFD **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus any C-BOMs at the acute phase of rehabilitation for knee flexors of the non-injured-limb for the experiment group condition.

5.6.1d - The relationship among P-BOMs versus C-BOMs at the acute phase of rehabilitation for knee extensors (non-injured limb) for PPM rehabilitation group only (n = 23)

A total of 45 correlations were found while evaluating P-BOMs versus. C-BOMs as evaluated by the knee extensors of the non-injured limb. From this total of 45 correlations, 2/45 (4.4%) correlation coefficients were found to be significant at $p < 0.05$ (x1) and $p < 0.01$ levels (x1). The KOOS component (Symptoms) score was significantly correlated with PF ($r = -0.42$; $p < 0.05$; $n = 23$); suggesting a low (negative) relationship between KOOS (Symptoms) with PF **(TABLE 6**; p. 126**)**. In the remaining significant correlation coefficient, the IKDC was significantly correlated with RFD ($r = -0.42$; $p < 0.05$; $n = 23$); suggesting a moderate (negative) relationship between IKDC and RFD **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus any C-BOMs at the acute phase of rehabilitation for knee extensors of the non-injured-limb for the experiment group.

5.6.2 - The relationships among P-BOMs and C-BOMs at the intermediate phase of rehabilitation

5.6.2a - The relationship among P-BOMs and C-BOMs at the intermediate phase (of rehabilitation for knee flexors (injured limb) for PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs as evaluated by the knee flexors of the injured limb. From this total of 54 correlations, 13/54 (20%) correlations were found to be significant at $p < 0.05$ (x3), $p < 0.01$ (x1), and $p < 0.001$ (x1) levels. The VAS (Pain) was significantly correlated with PF ($r = -0.43$; $p < 0.05$; $n = 23$) and versus SMP-FE ($r = 0.42$; $p < 0.05$; $n = 23$); suggesting a low (positive) relationship between VAS (Pain) and PF, and a low (negative) relationship between VAS (Pain) with SMP-FE **(TABLE 6**; p. 126**)**.

The Lysholm was found to be significantly correlated with the Single-Leg Hop for distance ($r = -0.51$; $p < 0.01$; $n = 23$) and versus PF ($r = 0.46$; $p < 0.05$; $n = 23$), and versus SMP-FE ($r = -0.46$; $p < 0.05$; $n = 23$); suggesting the Lysholm was moderately (negatively) correlated with the Single-Leg Hop for distance, and for the PF and SMP-FE, a low (positive) and low (negative) relationships were found, respectively **(TABLE 6**; p. 126**)**.

The KOOS component (Symptoms And Function) scores were found to be significantly correlated to the Single-Leg Hop for distance (Symptoms: $r = -.51$ ($p < 0.01$; $n = 23$; Function: $r = -0.48$ $p < 0.01$; $n = 23$), respectively; suggesting a low (negative) relationship between KOOS component (Function) score, and a moderate (negative) relationship between KOOS component (Symptoms) score with the Single-Leg Hop for distance **(TABLE 6**; p. 126**)**. Similarly, the KOOS component (Symptoms) scores was significantly correlated with PF ($r = -0.50$; $p < 0.01$; $n = 23$) and versus RFD ($r = 0.43$; $p < 0.05$; $n = 23$); suggesting a low (negative) relationship between RFD, and a moderate (negative) relationship with PF with the KOOS (Symptoms) component score. Moreover, the KOOS component (Pain and Function) scores were also significantly correlated with RFD (versus Pain: $r = 0.51$; $p < 0.01$; $n = 23$; versus Function: $r = 0.46$; $p < 0.05$; $n = 23$); suggesting a moderate (positive) and low (positive) relationships between KOOS component scores, respectively **(TABLE 6**; p. 126**)**.

In the last remaining significant correlation coefficient, the Performance Profile (injured limb) was significantly correlated with PF ($r = 0.55$; $p < 0.01$; $n = 23$); suggesting a moderate (positive) relationship between the Performance Profile (injured limb) and PF **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs at the intermediate phase of rehabilitation for knee flexors of the injured-limb for the experiment group condition.

5.6.2b - The relationship among P-BOMs versus C-BOMs at the intermediate phase (6-12 weeks) of rehabilitation for knee extensors (injured limb) for (PPM) rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs (as above) as evaluated by the knee extensors of the injured limb. From this total of 54 correlations, 13/54 (20%) correlation coefficients were found to be significant at $p < 0.05$ (x3), $p < 0.01$ (x7), and $p < 0.001$ (x3) levels. The VAS (Pain) was significantly correlated with PF ($r = -0.47$; $p < 0.05$; $n = 23$) and SMP-FE ($r = 0.60$; $p < 0.001$; $n = 23$); suggesting a low (negative) relationship between VAS (Pain) with PF, and a moderate (positive) relationship between VAS (Pain) with SMP-FE **(TABLE 6; p. 126).**

The IKDC was significantly correlated with RFD ($r = -0.55$; $p < 0.01$; $n = 23$) and SMP-FE ($r = -0.53$; $p < 0.001$; $n = 23$); suggesting a moderate (negative) relationships among RFD and SMP-FE with the IKDC. In the latter, SMP-FE was similarly correlated with the Lysholm ($r = -0.58$; $p < 0.001$; $n = 23$); suggesting a moderate (negative) relationship between the Lysholm and SMP-FE. Furthermore, the Lysholm was significantly correlated with Single-Leg Hop for distance ($r = 0.51$; $p < 0.01$; $n = 23$); suggesting a moderate (negative) relationships between the Lysholm and Single-Leg Hop for distance **(TABLE 6**; p. 126**)**.

The KOOS component (function, symptoms, QoL, and sport/rec) scores were significantly correlated versus range of C-BOMs (Single-Leg Hop for distance, PF, RFD, and SMP-FE). More specifically, KOOS component (QoL) score was significantly correlated versus PF ($r = 0.54$; $p < 0.001$; $n = 23$) suggesting a moderate (positive) relationship between KOOS component (QoL) score with PF. Similarly, the KOOS (Symptoms: $r = -0.51$; $p < 0.01$; $n = 23$; Function: $r = -0.48$; $p < 0.01$; $n = 23$) were significantly correlated with Single-Leg Hop for distance, suggesting a low (negative) relationships among KOOS (Function) and a moderate (negative) relationship among the Single-Leg Hop for distance **(TABLE 6**; p. 126**)**.

The KOOS (Sport/rec) was significantly correlated with RFD ($r = 0.47$; $p < 0.05$; $n = 23$) and versus EMD ($r = -0.43$; $p < 0.05$; $n = 23$); suggesting a low (positive) relationship between KOOS component (Sport/rec) score with RFD, and a low (negative) relationship between KOOS component (Sport/rec) score with EMD. The KOOS component (Symptoms: $r = -0.57$; $p < 0.01$; $n = 23$, and Function: $r = 0.64$; $p < 0.01$; $n = 23$) scores were significantly correlated with SMP-FE; suggesting a moderate (positive) relationships among KOOS components scores (as above) with SMP-FE **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs at the intermediate phase of rehabilitation for knee extensors of the injured-limb for the experiment group condition.

5.6.2c - The relationship between P-BOMs and C-BOMs at the intermediate phase of rehabilitation for knee flexors (non-injured limb) for the PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs as evaluated by the knee flexors of the non-injured limb. From this total of 54 correlations, 10/54 (18.5%) correlation coefficients were found to be significant at $p < 0.05$ (x4), $p < 0.01$ (x5), and $p < 0.001$ (x1) levels. The VAS (Pain) was significantly correlated with PF ($r = -0.52$; $p < 0.01$; $n = 23$) and versus Single-Leg Hop for distance ($r = -0.42$; $p < 0.05$; $n = 23$); suggesting a moderate (negative) relationship between VAS (Pain) with PF, and a low (negative) relationship between VAS (Pain) with Single-Leg Hop for distance **(TABLE 6**; p. 126**)**. In the latter, the Lysholm was significantly correlated with the Single-Leg Hop for distance ($r = 0.46$; $p < 0.05$; $n = 23$); suggesting a low (positive) relationship between the Lysholm and the Single-Leg Hop for distance **(TABLE 6**; p. 126**)**.

The KOOS component (Function, Symptoms, Qol, and Sport/rec) scores were significantly correlated versus a range of C-BOMs (Single-Leg Hop for distance, PF, EMD, and SMP-FE). For KOOS component (Symptoms: $r = -0.68$; $p < 0.001$; $n = 23$ and Function: $r = -0.49$; $p < 0.01$; $n = 23$) score were significantly correlated with PF; suggesting a moderate (negative) relationship between KOOS component (Symptoms) scores with PF, and a low (negative) relationship between KOOS component (Function) scores with PF **(TABLE 6**; p. 126**)**. Similarly, the KOOS component (Symptoms: $r = -0.55$; $p < 0.01$; $n = 23$; function: $r = -0.49$; $p < 0.01$; $n = 23$) scores were significantly correlated with Single-Leg Hop for distance; suggesting a moderate (negative) and low (negative) relationships among KOOS component (Symptoms and Function) scores, respectively. Similarly, KOOS component (Sport/rec) score was significantly correlated with EMD ($r = -0.43$; $p < 0.05$; $n = 23$) suggesting a low (negative) relationship **(TABLE 6**; p. 126**)**. With a slightly higher moderate (negative) correlation coefficient found ($r = -0.52$; $p < 0.01$; $n = 23$), suggests the KOOS component (QoL) scores was significantly correlated with ATFD. In the latter, ATFD was significantly correlated with IKDC ($r = 0.46$; $p < 0.05$; $n = 23$); suggesting a low (positive) relationship between IKDC with ATFD **(TABLE 6**; p. 126**)**.

No other significant relationships were found among P-BOMs versus C-BOMs at the intermediate phase of rehabilitation for knee flexors of the non-injured-limb for the experiment group condition.

5.6.2d - The relationship among P-BOMs versus C-BOMs at the intermediate phase of rehabilitation for knee extensors (non-injured limb) for PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs as evaluated by the knee extensors of the non-injured limb. From this total of 54 correlations, 14/54 (25.9%) correlation coefficients were found to be significant at $p < 0.05$ (x6), $p < 0.01$ (x5), and $p < 0.001$ (x3) levels.

The VAS (Pain) was significantly correlated with PF ($r = -0.52$; $p < 0.01$; $n = 23$) and versus Single-Leg Hop for distance ($r = -0.42$; $p < 0.05$; $n = 23$); suggesting a moderate (negative) relationship between VAS (Pain) with PF, and a low (negative) relationship between VAS (Pain) with Single-Leg Hop for distance **(TABLE 6**; p. 126**)**. In the latter, the Lysholm was significantly correlated with the Single-Leg Hop for distance ($r = 0.47$; $p < 0.05$; $n = 23$); suggesting a low (positive) relationship between the Lysholm with the Single-Leg Hop for distance **(TABLE 6**; p. 126**)**.

The IKDC was found to be significantly correlated with ATFD ($r = 0.46$; $p < 0.05$; $n = 23$), and versus RFD ($r = -0.47$; $p < 0.05$; $n = 23$), and versus EMD ($r = 0.48$; $p < 0.05$; $n = 23$), and versus SMP-FE ($r = -0.70$; $p < 0.001$; $n = 23$); suggesting the IKDC (versus ATFD and versus EMD) suggested a moderate (positive) relationship, and IKDC (versus RFD) reported a moderate (negative) relationship. Noticeably, the highest correlation coefficient (representing statistical and clinical relevance, ≤ 0.70) was found among the inter-correlation of IKDC versus SMP-FE suggesting high (negative) relationships **(TABLE 6**; p. 126**)**.

The KOOS component (Function, Symptoms, QoL, and Sport/rec) scores were significantly correlated versus a range of C-BOMs (Single-Leg Hop for distance, ATFD, PF, and SMP-FE). More specifically, the KOOS component (Symptoms: $r = -0.68$; $p < 0.001$, $n = 23$; and Function: $r = -0.49$; $p < 0.01$; $n = 23$) scores were significantly correlated with PF, suggesting a moderate (negative) relationship between KOOS component (Symptoms) score with PF, and a low (negative) relationship between KOOS component (Function) scores with PF. Similarly, the KOOS component (Symptoms: $r = -0.54$; $p < 0.01$; $n = 23$; and function: $r = -0.49$; $p < 0.01$; $n = 23$) scores were significantly correlated with Single-Leg Hop for distance; suggesting a moderate (negative) and low (negative) relationships among KOOS component (Symptoms and Function) scores with the Single-Leg Hop for distance, respectively. Similarly, KOOS component (QoL) score was significantly correlated with ATFD ($r = -0.52$; $p < 0.01$; $n = 23$) suggesting a moderate (negative) relationship between KOOS (QoL) with ATFD **(TABLE 6**; p. 126**)**.

In the remaining significant correlation coefficients, the KOOS component (Sport/rec: $r = 0.43$; $p < 0.05$; $n = 23$; QoL: $r = 0.62$; $p < 0.001$; $n = 23$) scores were significantly correlated with SMP-FE; suggesting a low (positive) and moderate (positive) relationships among SMP-FE and KOOS component scores, respectively **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs at the intermediate phase of rehabilitation for knee extensors of the non-injured-limb for the experiment group condition.

5.6.3 - The relationships among P-BOMs and C-BOMs at the late phase of rehabilitation

5.6.3a - The relationship among P-BOMs versus C-BOMs at late phase of rehabilitation for knee flexors (injured limb) for PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs evaluated by the knee flexors of the injured limb. From this total of 54 correlations, 12/54 (22.2%) correlation coefficients were found to be significant at $p< 0.05$ (x6), $p< 0.01$ (x1), and $p< 0.001$ (x5) levels.

The VAS (Pain) was significantly correlated with PF ($r = 0.71$; $p< 0.001$; $n = 23$) and versus EMD ($r = 0.91$; $p< 0.001$; $n = 23$); suggesting a high (positive) relationship between VAS (Pain) with PF, and a very high (positive) relationship between VAS (Pain) with EMD **(TABLE 6**; p. 126**)**. Similarly, the IKDC was evaluated to the same C-BOMs (versus PF: $r = -0.42$; $p< 0.05$; $n = 23$; and versus EMD: $r = -0.69$; $p< 0.001$; $n = 23$), respectively, suggesting that PF was low (and negatively) correlated with IKDC, and the EMD was moderately (and negatively) correlated with IKDC **(TABLE 6**; p. 126**)**.

The Lysholm was found to be significantly correlated with EMD ($r = -0.48$; $p< 0.05$; $n = 23$) and versus SMP-FE ($r = -0.43$; $p< 0.05$; $n = 23$) suggesting for the Lysholm versus SMP-FE and EMD, and low (negative) relationships were found **(TABLE 6**; p. 126**)**.

The KOOS component (Function) scores were significantly correlated with the Single-Leg Hop for distance (versus Function: $r = -0.43$; $p< 0.05$; $n = 23$), and SMP-FE (versus Function: $r = 0.56$; $p< 0.05$; $n = 23$); suggesting low (negative) and moderate (positive) relationships between KOOS component (Function) scores with Single-Leg Hop for distance and SMP-FE, respectively. In the latter, KOOS component (Pain: $r = -0.42$; $p< 0.05$; $n = 23$; and Sport/rec: $r = -0.48$; $p< 0.05$; n=) was significantly correlated with SMP-FE; suggesting low (positive) relationships among KOOS component scores (as above) and SMP-FE. In the remaining two correlation coefficients, KOOS component (QoL) scores were significantly correlated versus PF ($r = 0.65$; $p< 0.001$; $n = 23$) and versus EMD ($r = 0.87$; $p< 0.001$; $n = 23$); suggesting a moderate (positive) and a high (positive) relationships with PF and EMD among the KOOS component (QoL) scores, respectively **(TABLE 6**; p. 126**)**.

No other significant relationships were found among P-BOMs versus C-BOMs at the late phase of rehabilitation for knee flexors of the injured-limb for the experiment group condition.

5.6.3b - The relationship among P-BOMs versus C-BOMs at late phase of rehabilitation for knee extensors (injured limb) for PPM rehabilitation group only (n =23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs as evaluated by the knee extensors of the injured limb. From this total of 54 correlations, 8/54 (14.8%) correlation coefficients were found to be significant at $p< 0.05$ (x3) and $p< 0.001$ (x5) significance levels.

The VAS (Pain) was significantly correlated with PF ($r = 0.62$; $p< 0.001$; $n = 23$) and versus EMD ($r = 0.91$; $p< 0.001$; $n = 23$); suggesting a moderate (positive) relationship between VAS (Pain) with PF, and a very high (positive) relationship between VAS (Pain) with EMD **(TABLE 6**; p. 126**)**. Similarly, the IKDC was evaluated to the same C-BOMs (PF: $r = -0.48$; $p< 0.05$; $n = 23$; EMD: $r = -0.73$; $p< 0.001$; $n = 23$), respectively; suggesting that PF was low (and negatively) correlated with IKDC, and the EMD was highly (negatively) correlated with IKDC. In the latter, the Lysholm was significantly correlated with the EMD ($r = -0.47$; $p< 0.05$; $n = 23$); suggesting a low (negative) relationship between the Lysholm with EMD **(TABLE 6**; p. 126**)**.

The KOOS component (QoL and function) scores were significantly correlated with the Single-Leg Hop for distance (versus QoL: $r = -0.43$; $p< 0.05$; $n = 23$; and versus function: $r = -0.43$; $p< 0.05$); suggesting low (negative) relationships between KOOS component (QoL and function) scores with Single-Leg Hop for distance, respectively **(**TABLE 6; p. 126). No other significant relationships were found among P-BOMs versus C-BOMs at the late phase of rehabilitation for knee extensors of the injured-limb for the experiment group condition.

5.6.3c - The relationship among P-BOMs versus C-BOMs at late phase of rehabilitation for knee flexors (non-injured limb) for PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus C-BOMs evaluated by the knee extensors of the injured limb. From this total of 54 correlations, 10/54 (18.5%) correlation coefficients were found to be significant at $p< 0.05$ (x3), $p< 0.01$ (x1), and $p< 0.001$ (x6) significance levels.

The VAS (Pain) was significantly correlated with PF ($r = 0.71$; $p< 0.001$; $n = 23$) and versus EMD ($r = 0.95$; $p< 0.001$; $n = 23$); suggesting a high (positive) relationship between VAS (Pain) with PF, and a very high (positive) relationship between VAS (Pain) with EMD **(TABLE 6**; p. 126**)**. Similarly, the IKDC was evaluated to the same C-BOMs (PF: $r = -0.46$; $p< 0.05$; $n = 23$; and EMD: $r = -0.76$; $p< 0.001$; $n = 23$), respectively; suggesting that PF was low (and negatively) correlated with IKDC, and the EMD was highly (and negatively) correlated. In the latter, the Lysholm was significantly correlated with the EMD ($r = -0.53$; $p< 0.01$; $n = 23$); suggesting a moderate (negative) relationship between the Lysholm with EMD **(TABLE 6**; p. 126**)**.

The KOOS component (Symptoms, Pain, Qol, and Sport/rec) scores were significantly correlated with the PF (versus QoL: $r = 0.71$; $p < 0.001$; $n = 23$), and vs RFD (versus Pain: $r = -0.44$; $p < 0.05$; $n = 23$), and versus RFD (versus Sport/rec: $r = -0.42$; $p < 0.001$; $n = 23$), and versus SMP-FE (versus Symptoms: $r = -0.61$; $p < 0.001$; $n = 23$), and versus EMD (versus QoL: $r = 0.90$; $p < 0.001$; $n = 23$); suggest RFD (versus Pain and Sport/rec) report low (negative) relationships **(TABLE 6**; p. 126**)**. Whilst KOOS component (Symptoms) score versus SMP-FE suggests a moderate (positive) relationship. Noticeably, the highest correlation coefficients (representing statistical and clinical relevance, ≤ 0.70) was found among the inter-correlation of KOOS (QoL) versus EMD, and KOOS (QoL) versus PF; suggesting a high (negative) relationship for PF versus KOOS component (QoL) score and a very high (positive) relationship between EMD and KOOS component (QoL) score **(TABLE 6**; p. 126**)**.

No other significant relationships were found among patient-based versus C-BOMs at the late phase of rehabilitation for knee flexors of the non-injured-limb for the experiment group condition.

5.6.3d - The relationship among P-BOMs and C-BOMs at late phase of rehabilitation for knee extensors (non-injured limb) for PPM rehabilitation group only (n = 23)

A total of 54 correlations were found while evaluating P-BOMs versus. C-BOMs (as above) evaluated by the knee extensors of the non-injured limb. From this total of 54 correlations, 7/54 (12.9%) correlation coefficients were found to be significant at $p < 0.05$ (x1), $p < 0.01$ (x1), and $p < 0.001$ (x5) significance levels.

The VAS (Pain) was significantly correlated with PF ($r = 0.71$; $p < 0.001$; $n = 23$) and versus EMD ($r = 0.91$; $p < 0.001$; $n = 23$); suggesting a high (positive) relationship between VAS (Pain) with PF, and a very high (positive) relationship between VAS (Pain) with EMD **(TABLE 6**; p. 126**)**. Similarly, the IKDC was evaluated to the same C-BOMs (PF: $r = -0.46$; $p < 0.05$; $n = 23$; and EMD: $r = -0.72$; $p < 0.001$; $n = 23$), respectively; suggesting that PF was low (negatively) correlated with IKDC, and the EMD was highly (negatively) correlated **(TABLE 6**; p. 126**)**. In the latter, the Lysholm was significantly correlated with the EMD ($r = -0.50$; $p < 0.01$; $n = 23$); suggesting a moderate (negative) relationship between the Lysholm with EMD **(TABLE 6**; p. 126**)**. No other significant relationships were found among P-BOMs versus C-BOMs at the late phase of rehabilitation for knee extensors of the non-injured-limb for the experiment group condition.

5.6.4 - Summary

5.6.4a - The relationship between the knee flexors and knee extensors of the injured-limb at pre-surgery, and at the acute, intermediate, and late phases of rehabilitation for the CON and PPM rehabilitation groups

The outcome of this section reports that dissimilar proportions (PPM: 17.4% versus CON 3.9%) of significant correlations ($p < 0.05$) were found for the knee flexors of the injured-limb at pre-surgery (6/54 versus 2/54), and at the acute (5/45 versus 1/45), intermediate (13/54 versus 5/54), and late phases (12/54 versus 0/54) of rehabilitation for the CON and PPM rehabilitation groups, respectively **(**see TABLE 42). Similarly, for the knee extensors of the injured-limb across the same pre-surgery (9/54 versus 1/54), acute (6/45 versus 2/45), intermediate (13/54 versus 6/54), and late (8/54 versus 6/54) phases of rehabilitation, a similar proportions of significant correlations ($p < 0.05$) were found for the CON (4.8%) and PPM rehabilitation groups (12.5%), respectively **(see TABLE 38** and **TABLE 39)**.

Furthermore, with respect to the knee flexors and knee extensors for the injured limb pertaining to the PPM and CON rehabilitation groups across pre-surgery, acute, intermediate, and late phases of rehabilitation, a comparable magnitude of correlations coefficients were observed. However, in relation to the interpretation of correlation coefficients that may indicate statistical significant ($r \geq 0.70$[95]), and suggested by correlation coefficient within 'high' or 'very high' categories (Hinkle et al., 2003) for the knee flexors and extensors (injured-limb) of the respective PPM and CON rehabilitation groups. Only three correlation coefficients were reported to be fulfil this criterion, which were found at the late phase of rehabilitation in the PPM rehabilitation group condition for the knee extensors (injured limb) only.

More specifically, EMD was significantly correlated with IKDC ($r = -0.73$; $p < 0.001$; $n = 23$) and versus VAS (Pain) ($r = 0.91$; $p < 0.001$; $n = 23$), and versus KOOS component (QoL) score; suggesting a high (negative) relationship between IKDC with EMD, and very high (positive) relationships between VAS (Pain) and KOOS (QoL) with EMD **(TABLE 6**; p. 126**)**. No other statistical/clinically relevant ($r \geq 0.70$) relationships were found among P-BOMs versus C-BOMs at pre-surgery, and at the acute, intermediate and late phases of rehabilitation for knee flexors and extensors as evaluated by the PPM and CON rehabilitation groups for the injured limb.

[95] Cut-off values are based on suggestions of previous literature (see Nunnally, 1978).

TABLE 38 - Inter-correlation among P-BOMs versus C-BOMs (total number of significant correlations found/from a maximum number analysed) for either positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group (n = 23) for the knee flexors (injured limb), respectively.

		PRE-SURGERY		**ACUTE PHASE** (0-6 WEEKS)		**INTERMEDIATE PHASE** (6-12 WEEKS)		**LATE PHASE** (12-24 WEEKS)	
Patient-based vs. clinician-based (experimental group)	**RANGE:**	**0.46** (1/54) **[-0.51 to -0.61]** (5/54)		**0.44 to 0.46** (2/45) **[-0.44 to -0.64]** (3/45)		**0.42 to 0.55** (7/54) **[-0.43 to -0.51]** (6/54)		**0.42 to 0.91** (7/54) **[-0.42 to -0.69]** (5/54)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:							1	
	High:							2	
	Moderate:		5		2	3	3	2	1
	Low:	1		2	1	4	3	2	4
	Negligible:								
Patient-based vs. clinician -based (control group)	**RANGE:**	**0.45 to 0.49** (2/54)		**[-0.44]** (1/45)		**0.60** (1/54) **[-0.48 to -0.62]** (4/54)			
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:					1	3	**NR**	
	Low:	2			1		1		
	Negligible:								

TABLE 39 - Inter-correlation among P-BOMs versus C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM (n = 23) and CON rehabilitation group condition (n = 23) for the knee extensors (injured limb), respectively.

Patient-based vs. clinician-based (experimental group)

	PRE-SURGERY			ACUTE PHASE (0-6 WEEKS)			INTERMEDIATE PHASE (6-12 WEEKS)			LATE PHASE (12-24 WEEKS)		
RANGE	**0.46** (1/54) **[-0.42 to -0.61]** (8/54)			**0.45** (1/45) **[-0.42 to -0.46]** (5/45)			**0.47 to 0.64** (6/54) **[-0.43 to -0.58]** (7/54)			**0.42 to 0.91** (4/54) **[-0.62 to -0.93]** (4/54)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**	**2**	
	High:			**High:**			**High:**			**High:**		**1**
	Moderate:		5	Moderate:			Moderate:	5	4	Moderate:	2	
	Low:	1	3	Low:	5	1	Low:	1	3	Low:		3
	Negligible:			Negligible:			Negligible:			Negligible:		

Patient-based vs. clinician -based (control group)

	PRE-SURGERY			ACUTE PHASE (0-6 WEEKS)			INTERMEDIATE PHASE (6-12 WEEKS)			LATE PHASE (12-24 WEEKS)		
RANGE	**0.42** (1/54)			**0.45** (1/45) **[-0.45]** (1/45)			**0.60** (1/54) **[-0.48 to -0.62]** (5/54)			**0.57** (1/54)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**		
	High:			**High:**			**High:**			**High:**		
	Moderate:			Moderate:			Moderate:	1	3	Moderate:	1	
	Low:		1	Low:	1	1	Low:		2	Low:		
	Negligible:			Negligible:			Negligible:			Negligible:		

5.6.4b - The relationship between the knee flexors and knee extensors of the non-injured limb at pre-surgery, and at the acute, intermediate, and late phases of rehabilitation for the CON and PPM rehabilitation groups

The outcome of this section reports that a dissimilar proportions (PPM: 12.1% versus CON 5.8%) of significant correlations ($p < 0.05$) were found for the knee flexors of the non-injured at pre-surgery (2/54 versus 1/54), and at the acute (3/45 versus 1/45), intermediate (10/54 versus 5/54), and late phases (10/54 versus 5/54) of rehabilitation for the CON and PPM rehabilitation groups, respectively **(**see **TABLE 40)**. Similarly, for the knee extensors of the non-injured limb across the same pre-surgery (7/54 versus 1/54), acute (2/45 versus 1/45), intermediate (14/54 versus 5/54), and late (7/54 versus 4/54) phases of rehabilitation, similar proportions of significant correlations ($p < 0.05$) were found for the CON (5.3%) and PPM rehabilitation groups (14.5%), respectively **(**see **TABLE 41)**.

Furthermore, with respect to the knee flexors and knee extensors for the non-injured limb for the PPM and CON rehabilitation groups across pre-surgery, acute, intermediate, and late phases of rehabilitation, a comparable magnitude of correlations coefficients was observed. However, in relation to the interpretation of correlation coefficients that may indicate statistical significance ($r \geq 0.70$), and suggested by correlation coefficients within the ‘high’ or ‘very high’ (categories) (see Hinkle et al., 2003) for the knee flexors and extensors (non-injured limb) of the respective PPM and CON rehabilitation groups. Only five correlation coefficients were reported to be fulfilling this criterion, which were found at the late phase of rehabilitation in the PPM rehabilitation group condition for the knee extensors (non-injured limb) only.

More specifically, EMD was significantly correlated with IKDC ($r = -0.73$; $p < 0.001$; $n = 23$) and versus VAS (Pain) ($r = 0.91$; $p < 0.001$; $n = 23$), and versus KOOS component (QoL) score; suggesting a high (negative) relationship between IKDC with EMD, and very high (positive) relationships between VAS (Pain) and KOOS (QoL) with EMD **(TABLE 6**; p. 126**)**. No other statistical/clinically relevant ($r \geq 0.70$) relationships were found among P-BOMs versus C-BOMs at pre-surgery, and at the acute, intermediate and late phases of rehabilitation for knee flexors and extensors as evaluated by the PPM and CON rehabilitation groups for the non-injured limb.

The PF was significantly correlated with VAS (Pain) ($r = 0.71$; $p < 0.001$; $n = 23$) and versus KOOS component (QoL) score ($r = 0.71$; $p < 0.001$; $n = 23$); suggesting high (positive) relationships between PF with VAS (Pain) and KOOS component (QoL) score **(TABLE 6**; p. 126**)**. Similarly, EMD was significantly correlated with VAS (Pain) ($r = 0.90$; $p < 0.001$; $n = 23$), versus KOOS component (QoL) score ($r = 0.91$; $p < 0.001$; $n = 23$), and versus IKDC ($r = 0.72$; $p < 0.001$; $n = 23$); suggesting very high (positive) relationships between EMD among VAS (Pain) and KOOS (QoL) component scores **(TABLE 6**; p. 126**)**. In regards to EMD versus IKDC correlation, a high (negative) relationship was found **(TABLE 6**; p. 126**)**.

No other significant relationships were found among P-BOMs versus C-BOMs at the late phase of rehabilitation for knee extensors of the non-injured-limb for the PPM rehabilitation group condition.

TABLE 40 - Inter-correlation among P-BOMs versus C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM and CON rehabilitation group condition (n = 23) for the knee flexors (non-injured limb), respectively.

	PRE-SURGERY			ACUTE PHASE (0-6 WEEKS)			INTERMEDIATE PHASE (6-12 WEEKS)			LATE PHASE (12-24 WEEKS)		
Patient-based vs. clinician-based (experimental group)	**RANGE**: **[-0.46 to -0.48]** (2/54)			**RANGE**: **0.46** (2/45) **[-0.42]** (1/45)			**RANGE**: **0.46** (2/54) **[-0.42 to -0.68]** (8/54)			**RANGE**: **0.71 to 0.95** (4/54) **[-0.42 to -0.76]** (6/54)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**	**2**	
	High:			**High:**			**High:**			**High:**	**2**	**1**
	Moderate:			Moderate:			Moderate:		4	Moderate:		2
	Low:		2	Low:	2	1	Low:	2	4	Low:		3
	Negligible:			Negligible:			Negligible:			Negligible:		
Patient-based vs. clinician -based (control group)	**RANGE**: **0.41** (1/54)			**RANGE**: **0.62** (1/45)			**RANGE**: **0.43 to 0.50** (3/54) **[-0.43 to -0.49]** (2/54)			**RANGE**: **0.50 to 0.52** (2/54) **[-0.44 to -0.48]** (3/54)		
	Interpretation	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**	**Interpretation**	**Pos.**	**Neg.**
	Very high:			**Very high:**			**Very high:**			**Very high:**		
	High:			**High:**			**High:**			**High:**		
	Moderate:			Moderate:	1		Moderate:	1		Moderate:	2	
	Low:		1	Low:			Low:	2	2	Low:		3
	Negligible:			Negligible:			Negligible:			Negligible:		

TABLE 41 - Inter-correlation among P-BOMs versus C-BOMs (total number of significant correlations found/from a maximum number analysed) for either a positive and/or negative relationships (reporting [minimum - maximum range] of correlation coefficients found) at pre-surgery, and at acute, intermediate, and late phase of rehabilitation for the PPM and CON rehabilitation group condition (n = 23) for the knee extensors (non-injured limb), respectively.

		PRE-SURGERY		ACUTE PHASE (0-6 WEEKS)		INTERMEDIATE PHASE (6-12 WEEKS)		LATE PHASE (12-24 WEEKS)	
Patient-based vs. clinician-based (experimental group)	**RANGE:**	**[-0.42 to -0.56]** (7/54)		**[-0.42 to -0.50]** (2/45)		**0.43 to 0.62** (5/54) **[-0.42 to -0.70]** (9/54)		**0.71 to 0.91** (4/54) **[-0.46 to -0.72]** (3/54)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:							**2**	
	High:						**1**	**2**	**1**
	Moderate:		2		1	1	4		1
	Low:		5		1	4	4		1
	Negligible:								
Patient-based vs. clinician -based (control group)	**RANGE:**	**0.44** (1/54)		**0.68** (1/45)		**0.43 to 0.46** (2/54) **[-0.43 to -0.49]** (3/54)		**0.50** (1/54) **[-0.44 to -0.48]** (3/54)	
	Interpretation	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**
	Very high:								
	High:								
	Moderate:			1				1	
	Low:	1				2	3		3
	Negligible:								

TABLE 42 - Correlation coefficients reported statistically significant ($p < 0.05$) and potentially clinically relevant ($r \geq 0.70$) for all inter-correlations computed amongst P-BOM at pre-surgery, and at rehabilitation phases (acute, intermediate, and late).

Rehabilitation group	**Phase of rehabilitation**	**P-BOM**	**vs.**	**C-BOM**	**Correlation coefficient**	**Significance level**	**Hinkle et al., (2003) Interpretation**
CON	Late	IKDC	**vs.**	KOOS (Function)	-0.8	0.001	High (negative)
PPM	Late	IKDC	**vs.**	KOOS (Pain)	-0.83	0.001	High (negative)
CON	Late	IKDC	**vs.**	KOOS (Pain)	-0.92	0.001	Very high (negative)
PPM	Intermediate	IKDC	**vs.**	KOOS (QoL)	-0.8	0.001	High (negative)
PPM	Late	IKDC	**vs.**	KOOS (QoL)	-0.91	0.001	Very high (negative)
CON	Late	IKDC	**vs.**	KOOS (QoL)	-0.71	0.001	High (negative)
PPM	Late	IKDC	**vs.**	KOOS (Sport/rec)	-0.8	0.001	High (negative)
CON	Late	IKDC	**vs.**	KOOS (Sport/rec)	-0.8	0.001	High (negative)
PPM	Acute	IKDC	**vs.**	Lysholm	0.77	0.001	High (positive)
CON	Late	IKDC	**vs.**	Lysholm	0.78	0.001	High (positive)
PPM	Late	IKDC	**vs.**	Lysholm	0.86	0.001	High (positive)
PPM	Acute	IKDC	**vs.**	VAS (Pain)	-0.71	0.001	High (negative)
PPM	Late	IKDC	**vs.**	VAS (Pain)	-0.81	0.001	High (negative)

Continued...

PPM	Acute	KOOS (Function)	**vs.**	KOOS (Pain)	0.86	0.001	High (positive)
CON	Late	KOOS (Function)	**vs.**	KOOS (Pain)	0.88	0.001	High (positive)
PPM	Late	KOOS (Function)	**vs.**	KOOS (Pain)	0.88	0.001	High (positive)
PPM	Intermediate	KOOS (Function)	**vs.**	KOOS (Symptoms)	0.75	0.001	High (positive)
PPM	Late	KOOS (Function)	**vs.**	KOOS (Symptoms)	0.71	0.001	High (positive)
CON	Pre-surgery	KOOS (Pain)	**vs.**	KOOS (Function)	0.91	0.001	Very high (positive)
CON	Late	KOOS (QoL)	**vs.**	KOOS (Pain)	0.74	0.001	High (positive)
PPM	Acute	KOOS (QoL)	**vs.**	KOOS (Sport/rec)	0.77	0.001	High (positive)
CON	Late	KOOS (Sport/rec)	**vs.**	KOOS (Function)	0.84	0.001	High (positive)
PPM	Late	KOOS (Sport/rec)	**vs.**	KOOS (Function)	0.8	0.001	High (positive)
CON	Late	KOOS (Sport/rec)	**vs.**	KOOS (Pain)	0.9	0.001	Very high (positive)
PPM	Late	KOOS (Sport/rec)	**vs.**	KOOS (Pain)	0.83	0.001	High (positive)
PPM	Late	KOOS (Sport/rec)	**vs.**	Lysholm	-0.88	0.001	High (negative)
PPM	Intermediate	KOOS (Function)	**vs.**	Lysholm	-0.83	0.001	High (negative)
CON	Late	KOOS (Function)	**vs.**	Lysholm	-0.85	0.001	High (negative)
PPM	Late	KOOS (Function)	**vs.**	Lysholm	-0.88	0.001	High (negative)
CON	Late	KOOS (Pain)	**vs.**	Lysholm	-0.84	0.001	High (negative)
PPM	Late	KOOS (Pain)	**vs.**	Lysholm	-0.9	0.001	Very high (negative)
CON	Late	KOOS (QoL)	**vs.**	Lysholm	-0.71	0.001	High (negative)
PPM	Late	KOOS (QoL)	**vs.**	VAS (Pain)	0.96	0.001	Very high (positive)

TABLE 43 - Correlation coefficients reported statistically significant ($p < 0.05$) and potentially clinically relevant ($r \geq 0.70$) for all inter-correlations computed amongst C-BOMs at pre-surgery, and at rehabilitation phases (acute, intermediate, and late).

Rehabilitation group	Phase of rehabilitation	Knee muscles	Limbs	P-BOM	vs.	C-BOM	Correlation coefficient	Significance level	Hinkle et al., (2003) Interpretation
PPM	Late	Knee Flexors	Injured	EMD	**vs.**	PF	0.83	0.001	High (positive)
PPM	Late	Knee extensors	Non-injured	EMD	**vs.**	PF	0.71	0.001	High (positive)

TABLE 44 - Correlation coefficients reported statistically significant ($p< 0.05$) and potentially clinically relevant ($r\geq 0.70$) for all inter-correlations computed amongst P-BOM and C-BOMs, evaluated together, at pre-surgery, and at rehabilitation phases (acute, intermediate, and late).

Rehabilitation group	**Phase of rehabilitation**	**Knee muscles**	**Limbs**	**P-BOM**	**vs.**	**C-BOM**	**Correlation coefficient**	**Significance level**	**Hinkle et al., (2003) Interpretation**
PPM	Intermediate	Knee extensors	Non-injured	IKDC	**vs.**	SMP-FE	-0.70	0.001	High (negative)
PPM	Late	Knee extensors	Injured	IKDC	**vs.**	EMD	-0.73	0.001	High (negative)
PPM	Late	Knee flexors	Non-injured	IKDC	**vs.**	EMD	-0.76	0.001	High (negative)
PPM	Late	Knee extensors	Non-injured	IKDC	**vs.**	EMD	-0.72	0.001	High (negative)
PPM	Late	Knee flexors	Injured	KOOS (QoL)	**vs.**	EMD	0.87	0.001	High (positive)
PPM	Late	Knee extensors	Injured	KOOS (QoL)	**vs.**	EMD	0.93	0.001	Very high (positive)
PPM	Late	Knee flexors	Non-injured	KOOS (QoL)	**vs.**	EMD	0.90	0.001	Very high (positive)
PPM	Late	Knee extensors	Non-injured	KOOS (QoL)	**vs.**	EMD	0.91	0.001	Very high (positive)
PPM	Late	Knee flexors	Non-injured	KOOS (QoL)	**vs.**	PF	0.71	0.001	High (positive)
PPM	Late	Knee extensors	Non-injured	KOOS (QoL)	**vs.**	PF	0.71	0.001	High (positive)
PPM	Late	Knee extensors	Injured	VAS (Pain)	**vs.**	EMD	0.91	0.001	Very high (positive)
PPM	Late	Knee flexors	Injured	VAS (Pain)	**vs.**	EMD	0.91	0.001	Very high (positive)
PPM	Late	Knee flexors	Non-injured	VAS (Pain)	**vs.**	EMD	0.95	0.001	Very high (positive)
PPM	Late	Knee extensors	Non-injured	VAS (Pain)	**vs.**	EMD	0.90	0.001	Very high (positive)
PPM	Late	Knee flexors	Injured	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)
PPM	Late	Knee flexors	Non-injured	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)
PPM	Late	Knee extensors	Non-injured	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)

5.7 - Discussion

This study investigated inter-correlations amongst P-BOMs, C-BOMs, and P-BOMs and C-BOMs together, in a clinical population having undergone ACLR surgery followed by 24 weeks of rehabilitation. Describing and understanding the strength of relationships might help determine the number of outcome measures required to correctly describe progression across a rehabilitation period, and help understand the hierarchy of importance of outcome measures to properly describe changes in functional capacity (Phillips et al., 2000). Unfortunately, this study's outcome does not support the use of a single P-BOM and/or C-BOM at pre-surgery or across the acute, intermediate and late rehabilitation phases, to accurately reflect knee performance with ACLD/ACLR patients. Also this study cannot judge with certainty the hierarchy of P-BOMs and C-BOMs that should be deployed within ACL rehabilitation phases. It would appear that both P-BOMs and C-BOMs might contribute to separate, but potentially important, aspects of functional capability (Akker-Scheek et al., 2008; Reid et al., 2007).

In total, 2,808 correlation coefficients were found in the three inter-correlations computed (i.e., P-BOMs, C-BOMs, and P-BOMs and C-BOMs together) at pre-surgery, and at the acute, intermediate and late phases of rehabilitation for PPM[96] and CON[97] rehabilitation groups **(TABLE 45)**. Among these 2,808 correlations, only 317 (11%) correlation coefficients were found to be statistically significant at a $p < 0.05$ level. In light of this, the outcome of this study should be considered with caution. As only 317/2,808 correlation coefficients were found to be significant ($p < 0.05$) within the three computed inter-correlations, this outcome may have resulted in false positives when a significant interaction was not found. There would be a 5% chance of relationships being reported that could have occurred randomly with no actual relationships existing. It is important to stress that statistical significance ($p < 0.05$) only indicates the degree of certainty that some relationship exists, but does not indicate any clinical importance (Malgady et al., 1986; Fethney, 2010). Further, the low significant/non-significant correlations found (317 versus 2,491), and the small number of correlations demonstrating clinical relevance ($r \geq 0.70 = 52$) give interesting insight towards describing an initial outcome for this study, with an incredible 98% of all correlation coefficients not reporting any statistical significance or clinical relevance[98].

[96] Performance Profile Management (PPM).

[97] Contemporary (CON) clinical practice.

[98] Only a small percentage of all the correlation coefficients fulfilled statistical ($p < 0.05$) or clinical relevance ($r \geq 0.70$) for the PPM (39/317) (12.3%) and CON (13/317) (4.1%) rehabilitation groups across pre-surgery, and at the acute, intermediate, and late phases of rehabilitation. This interpretation is based on clinical relevance ($r \geq 0.70$), by correlation coefficients within 'high' or 'very high' categories) (see Hinkle et al., 2003).

As reported by Di Fabio (1999), caution should be taken when low or moderate correlation coefficients are assigned a significant p-value, as the p-value alone may result in the misinterpretation of the relationships between variables. Furthermore, the assignment of a significant p-value to a low to moderate correlation coefficient can potentially be misleading since statistical significance and poor relationships can occur simultaneously (Clark, 2001). Therefore, the magnitude of correlation coefficient values should be looked at before considering the level significance, as the correlation coefficient value presented indicates the degree to which two variables are correlated (Di Fabio, 1999; Greenfield et al., 1998), since a significant correlation coefficient does not automatically dictate a strong relationship between two variables (Clark, 2001).

Alongside what has been noted above, an understanding of correlation coefficients and the performing of regression analyses are important in allowing a means to describe relationships between variables, to predict one variable from another, or to statistically support a causal inference. However, the results of this study should be considered with caution with regards to the interpretation of the inter-correlation among P-BOMs and C-BOMs, due to the lack of significant correlation coefficients initially found. A regression analysis in this case was not warranted given the lack of statistical and clinical relevant relationships found. This study will therefore comment on which relationships indicated prominent statistical ($p< 0.05$) and clinical relevance ($r\geq 0.70$)[99] and would allow an understanding of the hierarchy of outcome measures demonstrating significant and clinical relevance.

[99] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

TABLE 45 - Frequency (and percentage, %) of correlation coefficients for all inter-correlations computed (P-BOMs, C-BOMs, and P-BOMs versus C-BOMs) shown to be statistically significant (p< 0.05) for CON and PPM rehabilitation groups, and where possible, for the injured and non-injured limbs associated with the knee flexors and knee extensors are presented.

	PRE-SURGERY			
	Control/experimental (n=46)			
PBOMs vs. PBOMs	24/28 (85.7%)			
	Injured		Non-injured	
	Flex.	Ext.	Flex.	Ext.
Clin-BOMs vs. Clin-BOMs	2/15 (13.3%)	1/15 (6.7%)	2/15 (13.3%)	3/15 (20.0%)
PBOMs vs. Clin-BOMs	2/54 (3.7%)	5/54 (9.3%)	1/54 (1.9%)	0/54 (0.0%)

	ACUTE PHASE (0-6 WEEKS)							
	Control (n=23)				Experimental (n=23)			
PBOMs vs. PBOMs	10/28 (35.7%)				15/28 (53.6%)			
	Injured		Non-injured		Injured		Non-injured	
	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.
Clin-BOMs vs. Clin-BOMs	1/10 (10.0%)	0/10 (0.0%)	1/15 (6.7%)	0/15 (0.0%)	1/10 (10.0%)	2/10 (20.0%)	3/15 (20.0%)	3/15 (20.0%)
PBOMs vs. Clin-BOMs	1/45 (2.2%)	2/45 (4.4%)	1/54 (1.9%)	1/54 (1.9%)	5/45 (9.3%)	6/45 (11.1%)	3/54 (5.6%)	2/54 (3.7%)

	INTERMEDIATE PHASE (6-12 WEEKS)							
	Control (n=23)				Experimental (n=23)			
PBOMs vs. PBOMs	7/28 (25%)				12/28 (42.9%)			
	Injured		Non-injured		Injured		Non-injured	
	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.
Clin-BOMs vs. Clin-BOMs	1/15 (6.7%)	4/15 (26.7%)	2/15 (13.3%)	2/15 (13.3%)	2/15 (13.3%)	0/15 (0.0%)	0/15 (0.0%)	1/15 (6.7%)
PBOMs vs. Clin-BOMs	5/54 (9.3%)	6/54 (11.1%)	5/54 (9.3%)	5/54 (9.3%)	13/54 (24.1%)	13/54 (24.1%)	10/54 (18.5%)	14/54 (25.9%)

	LATE PHASE (12-24 WEEKS)							
	Control (n=23)				Experimental (n=23)			
PBOMs vs. PBOMs	20/28 (71.4%)				27/28 (96.4%)			
	Injured		Non-injured		Injured		Non-injured	
	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.
Clin-BOMs vs. Clin-BOMs	1/15 (6.7%)	2/15 (13.3%)	2/15 (13.3%)	2/15 (13.3%)	2/15 (13.3%)	3/15 (20.0%)	3/15 (20.0%)	3/15 (20.0%)
PBOMs vs. Clin-BOMs	0/54 (0.0%)	1/54 (1.9%)	5/54 (9.3%)	4/54 (7.4%)	12/54 (22.2%)	8/54 (14.8%)	10/54 (18.5%)	7/54 (13.0%)

5.7.1 - To evaluate the influence of anthropometric (i.e., BMI etc.) and orthopaedic-related factors (i.e., time from ACL injury to ACLR surgery etc.) on relationships of P-BOMs and C-BOMs

It is firstly important to address where the correlational data was derived. The raw data/scores of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) from Study 4 **(Chapter 7: Intervention RCT investigation)** evaluated at assessment occasions (pre-surgery, weeks 6, 12, 24 weeks post-ACLR surgery) were used to formulate this correlation study **(Study 2)**. It was therefore necessary to determine whether the PPM and CON rehabilitation groups demonstrated any significant differences amongst P-BOMs and C-BOMs, including demographically-, anthropometrically-, and orthopedically-relevant characteristics at pre-surgery. Baseline group mean comparisons were performed using separate one-way ANOVAs involving independent groups (PPM and CON)[100]. Only age at surgery was found to be significant which was greater with the PPM rehabilitation group (35.0 ± 14.2 years) than the CON rehabilitation group (27.6 ± 9.5 years) [$F_{(1, 44)} = 4.3$; $p< 0.04$]. Although age at surgery showed significant differences between PPM and CON groups, further correlational analyses showed age had no significant relationship differences with any other P-BOMs or C-BOMs, either at pre-surgery or during subsequent assessment occasions (weeks 6, 12, 24 weeks post-ACLR surgery), suggesting it would not be influential in subsequent analyses.

Further, the fact that no differences were observed between the mean group responses of the patients in the PPM and CON rehabilitation groups, as evaluated by P-BOMs and C-BOMs, with no statistical adjustments for the anthropometric characteristics or orthopedically-relevant factors, confirms that these factors do not influence post-ACLR rehabilitation outcomes at pre-surgery. It was therefore now possible to pool PPM and CON rehabilitation groups together, totalling 46 participants as opposed to 23 per rehabilitation group which would be evaluated separately (n = 23). This may offer greater statistical robustness and make it possible to better identify possible relationships between P-BOMs and C-BOMs at pre-surgery. However, for the remaining rehabilitation phases (acute, intermediate, and late), the PPM and CON rehabilitation group were evaluated separately[101].

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[100] Consult p. 322 for full description of baseline group mean comparisons using separate one-way ANOVAs involving independent groups (PPM and CON)[100].

[101] The novelty of this study (addressing the secondary clinical research question: p. 57) is the evaluation of the contralateral (non-injured) limb and knee flexors and knee extensors of both the injured and non-injured limbs. Indeed, the inclusion of a non-injured limb has yet to be thoroughly presented in correlational studies to date (Sernet et al., 1999) and its evaluation will allow an understanding of the differences between the limbs. Although a degree of physiological de-conditioning of the non-injured leg is expected due to altered physiological loading in the period between injury and surgery, the inclusion of this leg nevertheless represents a best estimate of a reference (baseline) for performance and functional capability following ACL injury (Gleeson et al., 2008; Bailey et al., 2015).

From this standpoint, PPM and CON would need to be evaluated separately, as it would be necessary to evaluate whether any differences between the CON and PPM rehabilitation groups occurred within the random allocation of patients to these groups, resulting in differences (randomly), or in fact whether the RCT (i.e., the intervention of the PPM rehabilitation group) had affected the significant correlation outcome ($p< 0.05$) found.

5.7.2 - To critically evaluate the relationship amongst P-BOMs and C-BOMs by the three computed inter-correlations (amongst P-BOMs, C-BOMs, and P-BOMs and C-BOMs together) pre-ACLR surgery and within the acute, intermediate, and late phases of rehabilitation

It was firstly hypothesised *a priori* that the inter-correlation among P-BOMs (i.e., VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) at pre-surgery and within subsequent rehabilitation phases would demonstrate the highest strength of correlations compared to C-BOMs (i.e., Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE), also being investigated. The inter-correlation among P-BOMs reported 137/224 (62.1%) statistically significant ($p< 0.05$) correlation coefficients at pre-surgery, and at the acute, intermediate, and late phases of rehabilitation. For the inter-correlation among C-BOMs which additionally evaluated the knee flexors and knee extensors separately for the injured and non-injured limbs, the C-BOMs reported considerably lower proportions of statistically significant correlations. For the inter-correlation among C-BOMs for the knee flexors of the injured limb, only 10/110 (9.1%) of correlation coefficients were found to be statistically significant ($p< 0.05$). Similarly, for the knee extensors (injured), knee flexors (non-injured), and knee extensors (non-injured), parallel proportions of statistically significant correlations were found, 11.8% (13/110), 10.0% (12/120) and 15.0% (18/120), respectively **(TABLE 46)**.

Overall, it would appear that inter-correlations amongst P-BOMs were more consistently reported to be statistically significant ($p< 0.05$) at pre-surgery, and at the acute, intermediate, and late phases of rehabilitation in contrast with the inter-correlations amongst C-BOMs across the same occasions (137 versus 53, respectively). Nonetheless, the very low number of statistically significant correlations found in the separate evaluations, with only a further 52 correlations from this total having potential clinical relevance (at $r\geq 0.70$ level)[102], 33 and 19, respectively **(**see **TABLE 42** [p. 259], **TABLE 43** [p. 261], and **TABLE 44** [p. 262]**)**, it has in fact been demonstrated that P-BOMs have no more relationships than C-BOMs in this population.

Of the statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$) correlation

[102] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

coefficients found, only a very small number of P-BOMs were found. The majority of inter-correlations were observed between the KOOS and its own associated component scores with the highest correlation coefficient between KOOS (Pain) versus KOOS (Function) reporting an r = 0.91 (p< 0.001) relationship[103]. The IKDC (a P-BOM) was largely reported to be correlated with KOOS component scores: Pain (r = -0.83 to -0.92, p< 0.001), Function (r = -0.80, p< 0.001), QoL[104] (r = -0.80 to -0.91, p< 0.001), and Sport/rec[105] (r = -0.80, p< 0.001). Previous research (Van Meer et al., 2013), reported similar relationships between IKDC and KOOS component scores for Pain (r = -0.68), Symptoms (r = -0.65), Function (r = -0.71), Sport/rec (r = -0.61), and QoL (r = -0.36), which were likewise all negatively correlated, however, Van Meer et al., (2013) within a similar evaluation time-point as the presented study, reported correlation coefficients that were noticeably smaller in strength relationships. The literature does suggest that the KOOS seem to capture more information about psychological and social health domains than the IKDC because of the number of questions used to measure these areas (Valier et al., 2015). A number of inter-correlations were reported for Lysholm and KOOS, again with several of the component scores (Pain, Function, Sport/rec, and Qol), all suggesting a similar magnitude of strength of relationships as in previous literature (r = -0.71 to -0.90, p< 0.001) (Risberg et al., 1999).

The remaining correlation coefficients found, which were observed between IKDC versus Lysholm (r = 0.77 to 0.86, p< 0.001), were comparable to previous research, demonstrating a high (positive) relationship of r = 0.80 (Briggs et al., 2009). However, the Lysholm versus IKDC within the same study by Van Meer et al., (2013), also reported a lower correlation which was negatively correlated (r = -0.62). For the VAS (Pain) versus IKDC (r = 0.71 to -0.81, p< 0.001); and VAS (Pain) versus KOOS (Qol) (r = 0.96, p< 0.001), they are all suggestive of a positive high to very high relationship, however, these relationships have not yet been evaluated in the literature.

[103] Consult **APPENDIX 8 (**p. 559) for the remainder of the computed inter-correlations for P-BOMs.

[104] Sport and Recreation - KOOS sub-scale.

[105] Quality of Life - KOOS sub-scale.

TABLE 46 - Outcome of inter-correlations among P-BOMs and C-BOMs associated with the knee flexors and knee extensors (total number of significant correlations found (p< 0.05)/from a maximum number [percentage, %]) at pre-surgery, and at acute, intermediate, and late phases of rehabilitation for the PPM and CON rehabilitation group condition (n = 23) for the knee flexors and knee extensors (injured and non-injured limbs), respectively.

				REHABILITATION				
	GROUP CONDITION	**KNEE FLEXORS/ EXTENSORS (INJURED/NON-INJURED LIMB).**	**PRE-SURGERY**	**ACUTE PHASE (0-6 WEEKS)**	**INTERMEDIATE PHASE (6-12 WEEKS)**	**LATE PHASE (12-24 WEEKS)**	**TOTAL**	
Inter-correlations amongst patient-based outcome measures	Control. (n=46)		**21.4%** (6/28)	**35.7%** (6/28)	**25.0%** (6/28)	**71.4%** (20/28)	**72.6%** (61/112)	**62.1%** (137/224)
	Experimental. (n=46)		**64.8%** (18/28)	**53.6%** (15/28)	**42.6%** (12/28)	**96.4%** (27/28)	**69.4%** (78/112)	
Inter-correlations amongst clinician-based outcome measures	Control. (n=23)	**Flexors (injured limb)**	**0.0%** (0/15)	**10.0%** (1/10)	**6.7%** (1/15)	**6.7%** (1/15)	**5.5%** (3/55)	**9.1%** (10/110)
	Experimental. (n=23)	**Flexors (injured limb)**	**13.3%** (2/15)	**10.0%** (1/10)	**13.3%** (2/15)	**13.3%** (2/15)	**12.7%** (7/55)	
	Control. (n=23)	**Extensors (injured limb)**	**6.7%** (1/15)	**0.0%** (0/10)	**26.7%** (4/15)	**13.3%** (2/15)	**12.7%** (7/55)	**11.8%** (13/110)
	Experimental. (n=23)	**Extensors (injured limb)**	**0.0%** (0/15)	**20.0%** (3/10)	**0.0%** (0/15)	**20.0%** (3/15)	**11.0%** (6/55)	
	Control. (n=23)	**Flexors (non-injured limb)**	**13.3%** (2/15)	**6.7%** (1/15)	**13.3%** (2/15)	**13.3%** (2/15)	**11.7%** (7/60)	**10.0%** (12/120)
	Experimental. (n=23)	**Flexors (non-injured limb)**	**0.0%** (0/15)	**20.0%** (2/15)	**0.0%** (0/15)	**20.0%** (3/15)	**8.3%** (5/60)	
	Control. (n=23)	**Extensors (non-injured limb)**	**20.0%** (3/15)	**0.0%** (0/15)	**13.3%** (2/15)	**13.3%** (2/15)	**11.7%** (7/60)	**15.0%** (18/120)
	Experimental. (n=23)	**Extensors (non-injured limb)**	**26.7%** (4/15)	**20.0%** (3/15)	**6.7%** (1/15)	**20.0%** (3/15)	**18.3%** (11/60)	

In summary, the correlation coefficients observed within this study (as above) lacked sufficient frequency to confidently establish that one P-BOM has any form of superiority over another, although it could be argued that since the select P-BOMs address similar facets and sub-components of dysfunction and disability (i.e., pain, symptoms, function, QoL, etc.) within the inventory of questions asked, some of the inter-correlations amongst P-BOMs did provide some support for convergence. In fact, a surprisingly large proportion of inter-correlations computed amongst P-BOMs had very few correlation relationships, therefore the first hypothesis, stating that P-BOMs would demonstrate the highest strength of correlations compared to C-BOMs at pre-surgery and at acute, intermediate and late phases of rehabilitation cannot be demonstrated and is rejected.

With regards to the inter-correlation among C-BOMs, evaluated separately, only two correlation coefficients were found to be statistically significant ($p < 0.05$) and potentially clinically relevant ($r \geq 0.70$) for C-BOMs: PF and EMD, evaluated for the knee flexors (injured limb) ($r = 0.83$; $p < 0.001$; $n = 23$) and knee extensors (non-injured limb) ($r = 0.71$; $p < 0.001$; $n = 23$) at the late phase of rehabilitation (12-24 weeks post-ACLR surgery), respectively, for the PPM rehabilitation group only. PF and EMD neuromuscular outcomes have been tentatively linked with dynamic stability of the knee and ACL injury and it could be speculated that this might be the reason why these two neuromuscular outcome measures were highly (positively) correlated (Minshull et al. 2011; Minshull et al. 2009). It was hypothesised that the inter-correlation among C-BOMs at pre-surgery and within subsequent rehabilitation phases (acute, intermediate, and late) would inter-correlate, but to a lesser extent than P-BOMs due to the extremely disparate nature of the outcome measures used. Now, considering that only two correlation coefficients were reported to be statistical significant ($p < 0.05$) and clinically relevant ($r \geq 0.70$), the presented results show that the inter-correlation amongst C-BOMs lacked frequency both at pre-surgery and across the 24-week rehabilitation period, also confirming that no C-BOM demonstrated any form of superiority over another. As such, it cannot therefore be ascertained that C-BOMs correlate to a lesser extent than P-BOMs, as insufficient relationships were found in both cases, thus, the second hypothesis is also rejected.

Of equal interest, although a very large proportion of C-BOMs were additionally computed for the knee flexors and knee extensors for the injured and non-injured limbs, neither of these additional correlations were statistically significant either ($p < 0.05$), with only two relationships found to be potentially clinically relevant ($r \geq 0.70$). Noteworthy though is the fact that P-BOMs produced the highest proportion of correlation coefficients ($r \geq 0.70$) within the late phases of rehabilitation for the CON (12/20) and PPM (12/13) rehabilitation groups, 60% and 92.3%, respectively, while the latter correlations were non-existent for a very large proportion of the potential relationships investigated among C-BOMs, with correlation coefficients only being found between PF versus EMD, also occurring towards the later stages of ACL rehabilitation.

However, being very speculative and conservative in the interpretation of these results, it could be hypothesised that it was only in the later stages of rehabilitation (at 6 months) that patients could perceive their own knee function accurately. Moreover, evidence from other populations (i.e., comparison of ACL patients versus healthy control groups) (Kong et al., 2012; Risberg et al., 1999a) and comparisons of ACL patients injured limbs to non-injured limbs (Baltaci et al., 2012), potentially confirms this. However, there is limited evidence for this and more research on this interaction would be needed to permit such conclusions. A more plausible explanation is heteroscedasticity of data (not statically evaluated here) is more likely in the PPM rehabilitation group condition (i.e., spreading out of data for larger values), potentially resulting in an increased significant relationship (Leys, Ley, Klein, Bernard, and Licata, 2013). Despite this potential intrusion of heteroscedasticity within the presented results, particularly in the PPM rehabilitation group, the likelihood that this occurred is very small given the very low number of statistically significant ($p < 0.05$) and clinically relevant ($r \geq 0.70$) correlations that were actually found.

Since the results of Study 2 did not report many relationships between P-BOMs and C-BOMs evaluated concomitantly during 24 weeks of ACL rehabilitation, it would be useful in future research to evaluate a range of P-BOMs and C-BOMs longer term, at 1 year or further post-ACLR surgery. Ardern et al. (2011a) have in fact reported that 67% of patients electing to undergo ACLR surgery fail to gain functional capability in the knee at 12 months' follow-up. Equally, a meta-analysis investigating return to sport following ACL injury found that only 63% of patients established pre-injury levels of sporting function at 12 months (Ardern, 2011b). Further investigations are needed to continue this evaluation between P-BOMs and C-BOMs more long term, and it may be more appropriate to further examine the same outcome measures (as well as other P-BOM/C-BOM outcomes used in practice) with other ACL-deficient and symptomatic populations (i.e., OA, TKA etc.) to reconfirm these results.

As lastly hypothesised, the inter-correlations among P-BOMs and C-BOMs evaluated concomitantly at pre-surgery, and within subsequent rehabilitation phases were expected to be weaker compared to P-BOMs and C-BOMs evaluated in isolation, since P-BOM and C-BOM outcomes quantify different aspects of recovery and function (disability versus impairment respectively) (Akker-Scheek et al., 2008; Reid et al., 2007; Stratford and Kennedy, 2006; Fitzgerald et al., 2001). Unfortunately, the outcome of this study did not reveal many strong relationships between P-BOMs and C-BOMs, evaluated together, with sufficient frequency at pre-surgery, or at any subsequent phase of rehabilitation. Thus, the outcome of this particular inter-correlation cannot be judged with confidence and the relationships found remain relatively speculative, warranting further investigation. The potential reasons for the lack of relationships found are discussed in Study

1 **(Chapter 3: Systematic review)**.

Among the very small number of inter-correlations between concomitantly evaluated P-BOMs and C-BOMs that were found to be statistically significant ($p< 0.05$) and potentially clinically relevant ($r\geq 0.70$), notably at the late phase of rehabilitation, the majority of correlation coefficients observed were between VAS (Pain) and PF[106] ($r = 0.71$, $p< 0.001$) versus EMD[107] ($r = 0.90$ to 0.95, $p< 0.001$). Similarly, PF and EMD were reported to be correlated with the KOOS[108] QoL component score only, $r = 0.71$ ($p< 0.001$) and $r = 0.90$ to 0.95 ($p< 0.001$), respectively. EMD was also shown to be correlated with the IKDC ($r = -0.72$ to -0.76, $p< 0.001$). Lastly, the IKDC versus SMP-FE only demonstrated clinical relevance at $r = -0.70$ ($p< 0.001$) at the intermediate phase of rehabilitation for the PPM rehabilitation group. With only two correlational studies (Gleeson et al., 2008, Yates et al., 2016) available which directly examine these neuromuscular outcome measures (PF, EMD), it is difficult to discuss the comparison of these presented results. Both studies evaluated the IKDC versus neuromuscular outcome measures (PF, EMD, RFD) and others (ATFD and SMP-FE) at 2 weeks pre-ACLR surgery, and 6, 8 and 10 weeks post-ACLR surgery, with no statistically significant correlations found for the IKDC (Gleeson et al., 2008, Yates et al., 2016), contrasting with previous literature (Christensen et al., 2015).

The absence of strong relationships and frequent linkage among P-BOMs and C-BOMs evaluated together further suggests that both P-BOMs and C-BOMs quantify different aspects of function and recovery that cannot be causally linked (Akker-Scheek et al., 2008; Reid et al., 2007), and, as mentioned before, that both methods of evaluating patient outcomes might be contributing to a separate, but potentially important aspects of functional capability. In light of this, it may not be possible to use one method of assessment in place of another, and both P-BOMs and C-BOMs may be required to complement patient assessment (Shaw et al., 2005).

If strong relationships had been found amongst the candidate outcome measures, it could have enabled the number of P-BOMs and C-BOMs required to assess patient outcomes post-ACLR surgery to be reduced in the future. This outcome is therefore important for the thesis as whole, since at the present time it remains unknown which outcomes should be deployed post-ACLR surgery (Howe et al., 2012), or the minimum number of either P-BOMs or C-BOMs required to properly describe changes in patients' functional or physical performance during ACL rehabilitation, and importantly, the dilemma remains as to whether P-BOMs or C-BOMs offer most validity (see Reiman and Manske, 2011), requiring further investigation.

[106] Peak Force (PF).
[107] Electromechanical Delay (EMD).
[108] Knee Injury and Osteoarthritis Outcome Score (KOOS).

Study 2 therefore corroborates the findings of Study 1 **(Chapter 3: Systematic review)**, i.e. that P-BOMs and C-BOMs cannot be judged appropriately to understand which outcomes should be deployed to correctly describe progression and to properly describe changes in functional capacity over an ACL rehabilitation period of 24 weeks (Phillips et al., 2000). Consequently, for all the outcome measures evaluated in this thesis, a reduction in the size of the battery of P-BOMs and C-BOMs applied does not seem advisable, therefore they must all be deployed in Study 4 **(Chapter 7: Intervention RCT investigations)** to assess patient outcomes following ACLR surgery.

Ideally, if this research did support a strong relationship among P-BOMs and C-BOMs evaluated concomitantly, this might have indicated that patients are indeed correctly scoring their own perceptions of capability (P-BOMs) versus their objective physical performance, as evaluated by C-BOMs. At the present time, however, this has yet to be observed, having potential implications for clinical practice which will be discussed shortly. Had such relationships occurred this could also have supported the future proxy use of P-BOMs as efficient substitutes for more complex C-BOMs, providing another means for assessing patient outcomes in a less pragmatic way, yet based on the results of this study, this proxy-use could not be demonstrated or recommended.

The very few statistically significant ($p< 0.05$) correlations found, with many lacking clinical relevance ($r\geq 0.70$) across the rehabilitation phases give credence to a potential mismatching of patients' perception of their capabilities to the objectively-derived measurements evaluated by C-BOMs assessed concomitantly, which may represent the true extent of executable functional performance capabilities. If the patient perceives they are better than their musculoskeletal and neuromuscular capabilities, then this could potentially increase the risk of further injury if they chose to undertake activities they were not properly prepared for (Terwee et al., 2011).

One important relationship was found between IKDC versus SMP-FE associated with the knee extensors of the non-injured limb ($r= -0.70$, $p< 0.001$) at the intermediate phase of rehabilitation for the PPM rehabilitation group only. Only sensorimotor performance (SMP-FE), the ability to scale volitional force and joint positioning precisely, has previously been causally linked with ACL injury in the literature (Caraffa, Cerulli, Projethi, Aisa, and Rizzo, 1996; Hewett, Myer, and Ford, 2006; Griffin et al., 2006), and it is reassuring that sensorimotor performance alongside the other neuromuscular outcome measures (PF, RFD, EMD) were also found to be statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$), as these neuromuscular outcomes have also been tentatively linked with dynamic stability of the knee and ACL injury and prevention (Caraffa et al., 1996, Borsa et al., 1998, Risberg, 1999, Fitzgerald et al., 2001, Hopper et al., 2002, Hewitt et al., 2006, Harreld et al., 2006, Griffin et al., 2006, Minshull et al., 2011, Renstrom et al., 2008, Gleeson et al, 2008, Minshull et al., 2009, Ardern et al., 2010, Thomee et al., 2011, Minshull et al., 2011, Sugimoto, Myer, Mckeon, and Hewett, 2012). Being very speculative, the presented correlation coefficient between a P-BOM and SMP-FE was for the non-injured limb at the intermediate rehabilitation phase, and it could be argued that it may not be possible for injured patients to accurately scale volitional force (as undertaken here) due to ACL injury, with this only being achievable in the non-injured leg.

Furthermore, a recent Systematic Review by Gokeler at al. (2012) found that sensorimotor performance had a low to moderate correlation with several P-BOMs (KOOS, Tegner, Lysholm, Cincinnati, and VAS) following ACLR surgery. The authors allude to the possibility that sensorimotor performance might only have limited clinical relevance in assessing function. Although the majority of studies in this review examined either JPS[109] or TTDPM[110] (C-BOMs), none investigated sensorimotor performance as evaluated by force production at a knee angle associated with a high incidence of ACL injury, as presented in this study (see p. 162). There is currently no standard test for knee joint proprioception and sensorimotor control (Roberts, Fridem, Stomberg, Lindstrand, and Moritz, 2000, Roberts, Ageberg, Anderson, and Friden, 2007), therefore future research would be required to evaluate other methods to determine the relevant role of the sensorimotor system and potential relationships to P-BOMs (Gokeler at al., 2012).

The novelty of this study **(Study 2)** (and the secondary clinical question of the thesis) was the addition of the Performance Profile with the three inter-correlations (P-BOMs, C-BOMs, and P-BOMs and C-BOMs together), it being hoped that inclusion of the Performance Profile would provide insight into the latter's correlational characteristics evaluated against commonly deployed P-BOMs and C-BOMs across 24 weeks of rehabilitation. Furthermore, following the recommendations of previous research, this study investigated the Performance Profile circumventing many of the previously reported limitations and weaknesses which included: small sample size, heterogeneity of waiting time from injury to surgery, uncontrolled rehabilitation, and assessed the relationships over a longer term (Gleeson et al., 2008; Yates et al., 2016).

Unfortunately, only 10 correlation coefficients were found to be statistically significant ($p < 0.05$) **(TABLE 47**; p. 277**)**. On examining all the reported correlation coefficients found at pre-surgery at all rehabilitation phases (acute, intermediate and late), no correlation coefficients reported any clinical relevance at the $r \leq 0.70$ level for the Performance Profile versus any P-BOMs and/or C-BOMs. Notwithstanding the fact that no performance correlation data has yet been fully investigated or reported in the literature, other than in two small-scale correlational studies (Gleeson et al. 2008; and Yates et al., 2016), and the very small number of relationships, all of which lacked clinical significance ($r \leq 0.70$), the Performance Profile results shall be discussed here as best possible despite these limitations.

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[109] Joint Position Sense (JPS).

[110] Threshold to Detect Passive Motion (TTDPM).

In the inter-correlations among Performance Profile and P-BOMs evaluated together, significant relationships ($p < 0.05$) were not found at either pre-surgery or at the acute phase of rehabilitation. The Performance Profile [non-injured] limb was significantly correlated with VAS (Pain) ($r = -0.59$; $p < 0.05$) at the intermediate phase, however, suggesting a moderate (negative) relationship. In addition to this correlation, and more prominently within the late phase of rehabilitation (five correlation coefficients were found) the Performance Profile [non-injured] limb was firstly significantly correlated versus Lysholm ($r = 0.61$; $p < 0.01$), and versus KOOS component scores (Symptoms and Function) ($r = -0.52$ to -0.59; $p < 0.05$). It is noteworthy, that each individualised Performance Profile was assessed for the injured and non-injured limbs separately for each participant at pre-surgery and across the rehabilitation phases, which had not been investigated before, with previous profiling studies evaluating both the injured and non-injured limbs collectively (Gleeson et al., 2008; Yates et al., 2016).

The results suggest that the Performance Profile of the respective limbs (injured versus non-injured limb) reported a moderate (positive) relationship at the late rehabilitation phase only ($r = 0.55$ to 0.62; $p < 0.05$), which could potentially be expected since at the end of rehabilitation (24 weeks post-ACLR surgery) 89% of participants were at pre-surgery levels for P-BOM and C-BOM outcomes. This may have been expected given that each leg was evaluated against the same individual profile items, thus, as firstly hypothesised, each leg and the respective profiles would address the same facets and, more importantly, the same individual constructs (i.e., items such as pain, symptoms, function, etc.) within the inventory of each patient's profile. The fact that this did occur at the late stage of rehabilitation does - very speculatively - implies that other P-BOMs inter-correlated amongst P-BOMs, should correlate in a similar manner. Alongside the previous argument, however speculative, it has also been suggested that patients are unable to accurately rate P-BOMs and C-BOMs (together) until the latter stages of rehabilitation.

In this study, each patient's Performance Profile was individualised with different items identified by themselves, however in future research it may be more practical to use a ready-prepared fixed profile with predetermined qualities/items as in previous profiling literature (D'Urso, Petrosso, and Robazza, 2002; Butler, 1997) allowing all participants to complete the same items (for injured and non-injured limbs). Future research should therefore evaluate which items (constructs) would be suitable for use in a generic fixed profile and attempt to determine whether allowing patients to create their own individualised profile would generate more or less correlations between P-BOMs and C-BOMs compared to a fixed profile.

The inter-correlation found among the Performance Profile and C-BOMs, evaluated together, were neither statistically significantly ($p < 0.05$) nor clinically relevant ($r \geq 0.70$) at pre-surgery. At the acute phase of rehabilitation, the Performance Profile (injured limb) was significantly correlated with SMP-FE ($r = 0.42$ to 0.45; $p < 0.05$) assessed by the knee extensors only, however there was a lack of clinical relevance ($r \geq 0.70$). The Performance Profile (non-injured limb) was significantly correlated with RFD ($r = 0.46$; $p < 0.05$; $n = 23$) assessed by the knee extensors only, again lacking sufficient clinical relevance ($r \geq 0.70$). Alongside these correlations, only one correlation coefficient was found within the intermediate phase of rehabilitation between the Performance Profile (injured limb) with PF of the injured knee flexors ($r = 0.55$; $p < 0.01$; $n = 23$). In contrast to previous findings in the literature, a created profile measuring individualised emotional responses post-ACL injury (Gleeson et al., 2008) was significantly ($p < 0.01$ - 0.05), highly correlated (Hinkle et al., 2003) with C-BOMs, which included neuromuscular outcomes of PF ($rs = 0.82$ to 0.85), EMD ($rs = 0.81$ to 0.84), and assessment of Anterior Tibio-Femoral Displacement (ATFD), the evaluation of knee laxity, which ranged from $rs = 0.68$ to 0.72 at pre-surgery, and at the acute phases of rehabilitation (0 to 6 weeks post-ACLR surgery) approaching the intermediate phases of rehabilitation (10 weeks post-ACLR surgery) for the knee flexors.

In Gleeson et al. (2008), the Performance Profile emotional disturbance scores decreased post-ACLR surgery, with emotional discrepancy scoring less (10 weeks post-ACLR surgery versus pre-surgery, 6, 8 weeks post-ACLR surgery). Higher Performance Profile emotional disturbance scoring was significantly ($p < 0.05$) correlated to higher ATFD scores (2, 8, 10 weeks post-ACLR surgery) ($rs = 0.68$, 0.72, 0.70, respectively). Other significant correlations ($p < 0.01$) were observed between emotional Performance Profiles scores and PF, EMD (8 weeks ($rs = 0.85$, -0.81, respectively) and 10 weeks ($rs = -0.82$, -0.84, respectively) post-ACLR surgery) with higher emotional disturbance scoring on Performance Profile related to muscular weakness and longer muscle-activation delays (pre-surgery, 8, 10 weeks post-surgery).

In contrast to all of the correlation coefficients reported above, Study 2 did not see the magnitude or strength of relationships found by Gleeson et al. (2008). However, since this study was conducted by the same research group as that by Gleeson et al. (2008) using the same testing equipment, subject population and pathologic condition and similar protocols in testing procedures. The differences between the two studies cannot be attributed to any of these factors (Wilk et al., 1994). One of the explanations for this difference could be that Gleeson et al. (2008) deployed an emotional Performance Profile while Study 2 incorporated only physical responses to injury, since it could be argued that emotional responses to injury do in fact correlate for this reason and would require further investigation.

TABLE 47 - Outcome of inter-correlations among P-BOMs and C-BOMs (knee flexors and knee extensors of the injured and non-injured limbs) associated with the Performance Profile at pre-surgery, and at acute, intermediate, and late phases of rehabilitation found to be statistically significant ($p < 0.05$). **NOTE**: No interactions were found indicating clinical relevance ($r \geq 0.70$).

		Performance Profile	vs.	Patient-based or clinician-based outcome measure	Correlation Coefficient.	Significance level.	Henkle et al. (2003) interpretation.
Inter-correlations amongst patient-based outcome measures	**Pre-surgery:**	**NR**	vs.	**NR**			
	Acute phase (0-6 weeks post-surgery):	**NR**	vs.	**NR**			
	Intermediate phase (6-12 weeks post-surgery):	Performance profile (non-injured)	vs.	VAS (pain)	-0.59	0.01	Moderate (negative)
	Late phase (12-24 weeks post-surgery):	Performance profile (non-injured)	vs.	KOOS (symptoms)	-0.59	0.01	Moderate (negative)
		Performance profile (non-injured)	vs.	KOOS (function)	-0.52	0.05	Moderate (negative)
		Performance profile (non-injured)	vs.	Lysholm	0.61	0.01	Moderate (positive)
		Performance profile (non-injured)	vs.	Performance profile (injured)	0.62	0.01	Moderate (positive)
		Performance profile (non-injured)	vs.	Performance profile (injured)	0.55	0.05	Moderate (positive)
Inter-correlations amongst patient-based and clinician-based outcome measures	**Pre-surgery:**	**NR**	vs.	**NR**			
	Acute phase (0-6 weeks post-surgery):	Performance profile (injured)	vs.	SMP-FE (extensors [injured])	0.42	0.05	Low (positive)
		Performance profile (non-injured)	vs.	RFD (flexors [non-injured])	0.46	0.05	Low (positive)
		Performance profile (injured)	vs.	SMP-FE (extensors [injured])	0.45	0.05	Low (positive)
	Intermediate phase (6-12 weeks post-surgery):	Performance profile (injured)	vs.	PF (flexors [injured])	0.55	0.01	Moderate (positive)
	Late phase (12-24 weeks post-surgery):	**NR**	vs.	NR			

Moreover, in Yates et al. (2016), it was found that there was in fact a mismatch in patients' perceptions (Performance Profile) versus their actual physical performance (evaluated by C-BOMs: PF, RFD, EMD, and SMP-FE), where a latency of two weeks was found. It was speculated that over this period of time from ACLR surgery to 10 weeks' post-rehabilitation, participants had achieved limited experience of stressing or testing the capability of the injured knee joint, and had become habituated to the 'feel' of the injured leg. This type of compensatory effect may have led to a patient-perceived scaling of response that under-estimated the extent of inter-limb discrepancy of C-BOM capabilities prior to ACLR surgery. The main difference between Gleeson et al. (2008) and Study 2 and Yates et al. (2016), was that the latter used physical responses to ACL injury and it can be argued that the physical responses did not correlate as well as emotional response did, however, the use of physical responses may have implications for clinical practice. Clinicians should be aware that participants are likely to considerably miscalibrate their true capabilities and perceive high levels of dysfunction over this initial period of (acute) rehabilitation.

5.8 - Conclusion and clinical implications

The results of this study **(Study 2)** further corroborate the outcomes of Study 1 **(Chapter 3: Systematic review)**. At the present time, there is insufficient research data to allow the relationships amongst P-BOMs, amongst C-BOMs, and between P-BOMs and C-BOM (together) to be speculated with any degree of certainty, highlighting the challenges faced by clinicians and researchers (Valier et al., 2015). These include determining the minimum number of either P-BOMs or C-BOMs required to properly describe changes in patients' functional or physical performance during their rehabilitation, and importantly, the dilemma of whether P-BOMs or C-BOMs offer most validity **(**Reiman and Manske, 2011**)**. At the outset, both Study 1 **(Chapter 3: Systematic review)** and the presented study **(Study 2)** reported a low number of statistically significant versus non-significant correlations, 117 versus 271 and 317 versus 2,491[111], respectively. Examination of the statistically significant ($p< 0.05$) correlation coefficients which demonstrated potential clinical relevance (at $r\geq 0.70$ cut-off[112]), provides interesting insight towards describing both the Systematic Review and study 2, whereby an incredible 91% and 98%[113] of all correlation coefficients, respectively, did not indicate any statistical significance ($p< 0.05$) or clinical relevance ($r\geq 0.70$).

[111] Evaluation of inter-correlations among: **(1 :)** P-BOMs; **(2 :)** C-BOMs; and **(3 :)** P-BOMs and C-BOMs together, before ACLR surgery, and within acute (0-6 weeks), intermediate (6-12 weeks), and late (12-24 weeks) rehabilitation phases.

[112] Cut-off values are based on suggestions from previous literature (see Nunnally, 1978).

[113] Study 1 (Systematic review): [($r\geq 0.70 = 36$) / 388 (total)] * 100 = 9.2]; ∴ 9.2 - 100 = 90.7 (rounded to 91%). Study 2 (Correlation): [($r\geq 0.70 = 52$) / 2808 (total)] * 100 = 1.8]; ∴ 1.8 - 100 = 98.1 (rounded to 98%).

Notably with the absence of strong relationships and frequent linkage among P-BOMs and C-BOMs, it can be further reasoned that each outcome measure might be contributing to a separate, but potentially important aspect of function and recovery, but with no causal linkage (Akker-Scheek et al., 2008; Reid et al., 2007; Stratford and Kennedy, 2006; Fitzgerald et al., 2001). Therefore, physiotherapists should avoid promoting a patient rehabilitative regime based on the development of aspects of performance focusing on a single outcome measure, and should continue to deploy a number P-BOMs and C-BOMs to comprehensively evaluate overall knee function from the perspective of both the patient and the physiotherapist.

With this said, there is insufficient correlational evidence in this study or in the literature to support the proxy use of P-BOMs as efficient substitutes for more complex objective-derived (clinician-based) outcome measures. The results of this study should be considered with extreme caution, with regards to the interpretation of the inter-correlation among P-BOMs and C-BOMs evaluated concomitantly, due to the lack of significant correlation ($p< 0.05$) coefficients actually found which were clinically relevant ($r\geq 0.70$). The extent and strength of relationships among P-BOMs and C-BOMs cannot therefore be judged with certainty and remain relatively speculative, warranting further investigation.

The outcome of the literature review **(Chapter 3: Systematic review)** found heterogeneity of P-BOMs and C-BOMs, with twenty-six P-BOMs and forty-six C-BOMs illustrating the diversity of outcome measures deployed in practice. Indeed, these studies were mostly non-comparable with no same P-BOMs being consistently evaluated with the same C-BOMs. Study 2 therefore evaluated a range of P-BOMs and C-BOMs simultaneously within a single clinical population.

The findings of both the Systematic Review **(Chapter 3)** and Study 2 showed a range of P-BOMs and C-BOMs which were significant and appropriately clinically relevant ($r\geq 0.70$). It had previously been suggested that the outcome measures required to correctly describe progression and understand the hierarchy of importance of outcome measures in order to properly describe changes in functional capacity still remains unknown. With greater confidence, the outcome of the systematic review[114] and **Study 2** have now confirmed that P-BOMs (IKDC, VAS [Pain], and KOOS [QoL]) and C-BOMs (PF, EMD and SMP-FE) demonstrate the highest form of potential clinical utility ($r \geq = 0.90$).

The disassociation between P-BOMs and C-BOMs found could be attributed to sub-optimal conditioning within rehabilitation therapy with the mismatching of patient-perceived capabilities to the objectively-derived measurements evaluated by C-BOMs (Terwee et al., 2011), which to some extent may allow a more accurate discrimination of actual functional performance and executable

[114] The following P-BOMs (Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance profile) and C-BOMs (Hop [6m-timed], Stairs Hopple (timed), ATFD, PF, PT, TW, and EMD) were found to have most clinical relevance ($r = 0.80$ to 0.90) from Study 1 **(Chapter 3: Systematic review)**.

capabilities. It is important for physiotherapists to be aware that if a patient's perception is mismatched to their actual function performance capabilities, this could increase the risk of further injury if the patient chooses to undertake activities they are not properly prepared for (Terwee et al., 2011); physiotherapists should therefore act appropriately to ensure this risk of further injury is minimised. Unfortunately, this study's outcome does not support the use of a single P-BOM and/or C-BOM at pre-surgery or across the acute, intermediate and late rehabilitation phases, to accurately reflect knee performance with ACLD/ACLR patients. Therefore, a reduction in the size of the battery of P-BOMs and C-BOMs cannot be envisaged, and all P-BOMs and C-BOMs must be deployed in Study 4 **(Chapter 7: Intervention RCT investigation)** to assess patient outcomes following ACLR surgery.

In summary, the findings of this study **(Study 2)** have similar implications for clinical practice as suggested in Study 1 **(Chapter 3: Systematic review)**. Several key implications for clinical practice have now been re-confirmed, thus, this study suggests that **(1 :)** with the absence of strong relationships which are infrequently linked among P-BOMs and C-BOMs, each outcome measure might be contributing to a separate, but potentially important aspect of function and recovery, but with no causal linkage; **(2 :)** the proxy-use of P-BOMs (including Performance Profile) as efficient substitutes for C-BOMs cannot be envisaged based on the results of this study; **(3 :)** the Performance Profile appeared to correlate sporadically amongst other outcome measures against which it had been evaluated, but overall, it was statistically and clinically irrelevant; **(4 :)** the lack of correlation among P-BOM and C-BOMs could potentially lead to sub-optimal conditioning within rehabilitation therapy, with patient's perceived capabilities being mismatched to the objectively-derived measurements; **(5 :)** the mismatch between patient perceptions and actual function performance capabilities could in fact increase the risk of further injury if the patient chose to undertake activities for which they are unprepared; **(6 :)** clinical practice should continue to deploy numerous P-BOMs and C-BOMs to holistically evaluate patient outcomes; and **(7 :)** physiotherapists should avoid promoting a patient rehabilitative regime based on the development of aspects of performance focusing on a single outcome measure.

CHAPTER SIX

STUDY 3

Single Measurement Reliability, Reproducibility and Responsiveness of the Performance Profile in Patients with Anterior Cruciate Ligament (ACL) Injury

6.1 - Introduction

Originally named the 'Self-Perception Map' (Butler, 1989), the 'Performance Profile' (Butler et al., 1992), as it is formally known today, is essentially an extension of the Repertory Grid (Fransella et al., 2004). Butler and Hardy (1992) originally proposed using this method to assess athletes' perceived needs followed by a tailored guided intervention management programme. However, only one study, conducted in 2011, has used this investigation design to examine the impact of a repeated performance-profiling intervention on athletes' intrinsic motivation (Weston et al., 2011b). That study's findings were encouraging, suggesting that single use of the Performance Profile led to no significant improvement in athletes' intrinsic motivation, while three repeated completions during a competitive six-week season improved motivation significantly. Quite interestingly in this study, athletes were instructed to select up to three items from those identified within their individual profile which required the greatest improvement. These items were then discussed with the athletes' coaches to determine how best to achieve these necessary improvements[115].

Application of the Performance Profile to a symptomatic population within individual orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways has yet to be studied, however, therefore, this is to be investigated in Study 4 **(Chapter 7: Intervention RCT investigation)**. The development and validation of new P-BOMs (Performance Profile) have been explicitly addressed (U.S. Department of Health and Human Services Food and Drug Administration, 2006), with respect to assessing reliability, validity, ability to detect change and interpretability (i.e., minimum important difference) of the outcome. **TABLE 48** (next page) sets out the aspects of the psychometric measurement properties that are essential to substantiating such use of the Performance Profile in clinical practice, whilst addressing the technique's clinical utility (appropriateness, acceptability and feasibility) (Valier et al., 2015).

At present, there is very little reliability data available on the Performance Profile with athletes, and with patients in a clinical setting this data is extremely limited (Yates et al., 2016). In clinical research, reliability is described as the first psychometric property that must be assessed because no test can be valid without being reliable (Portney and Watkins, 2000). Test-retest reliability (a method of testing the stability and reliability of a test instrument over time) is more relevant in a clinical medicine setting, because the items (constructs) being measured are heterogeneous. Hence, a repeatability study is required to help establish and quantify reproducibility

[115] Within the context of Study 4 **(Chapter 7: Intervention RCT investigation)**, a similar approach was deployed in which each participant was required to determine the relative importance of each self-perceived need, as in previous research (Weston et al., 2011b). In Study 4, participants were asked to rank their Performance Profile items in order of importance and those requiring greatest improvement (and priority of treatment) to achieve full recovery. The five areas identified from the ratings as most important from the patient's perspective were used to initiate discussions between the patient and physiotherapist on how best to achieve the desired improvements from the patient's perspective.

and thus provide an indication of the test-retest reliability of a measure (Batterham and George, 2003).

One concern with testing reliability using the test-retest method is that there is the potential for learning, carry-over, or recall effects (Frost et al., 2007), and when establishing a new measurement technique, both measurement variability and measurement error must be taken into consideration (Watson and Petrie, 2010). Test-retest reliability can also be affected by the length of time between test administrations (Marx, Menezes, Horovitz, Jones, and Warren, 2003), whereby a very short time interval makes the carry-over effects owing to memory, practice, or mood more likely, and a longer interval increases the chances that a change in physical function or emotional status could occur. Therefore, it would be important to habituate participants to the test procedures via an accommodation phase to control for potential learning effects, since only then can an accurate assessment of reliability be performed (Batterham and George, 2003).

Reliability is an assessment of the degree of consistency between multiple measurements of a variable. The reliability of an outcome measure concerns the extent to which the outcome yields the same results in repeated trials. The tendency toward consistency, found in repeated measurements, is referred to as reliability (Carmines and Zeller, 1979), therefore, reliability means consistency. It is the degree to which an instrument will give similar results for the same individuals at different times. Reliability can take on values of 0 to 1.0, inclusive. Cronbach's alpha simply provides an overall reliability coefficient for a set of variables. Cronbach's alpha method is used in this research to assess the consistency of the entire scale (variables). A Cronbach's alpha reliability value of 0.70 or higher suggests good reliability. Cronbach's alpha values ranging between 0.60 and 0.70 have been reported to be acceptable provided other indicators of a model's construct validity are good. High construct reliability indicates that internal consistency exists, meaning that the measures all consistently represent the same latent construct (Hair, Black, Babin, Anderson, and Tatham, 2006).

An essential requirement of all outcome measures, including that of the Performance Profile, is that it should be valid and reproducible or reliable (de Vet et al., 2006). Measurement precision in this context may be defined as the extent to which an athlete's Performance Profile representing their perceived current state at one testing occasion, can be reproduced in subsequent tests or trials conducted by the same participant under the same circumstances (Watson and Petrie, 2010). If a test or measurement tool cannot provide such reproducibility, then it cannot be considered valid and will therefore be classed as unreliable (Batterham and George, 2003; Watson and Petrie, 2010). However, if the repeatability and reproducibility of a measurement technique does indicate reliability, this implies better precision of single measurements and, potentially, more accurate tracking of changes in measurements for researchers or practitioners in clinical settings (Frost et al., 2007; Hopkins, 2000).

TABLE 48 - Criteria for selecting P-BOM and psychometric measurement components, edited and adapted from Valier and Kenneth, 2015. Definitions for each psychometric measurement component are as described by Mokkink et al., 2010, or as otherwise indicated.

Classification	Component	Definition
Essential elements:	**Reliability**	The degree to which the measurement is free from measurement error. [116]
	Validity	The degree to which a P-BOM instrument measures the constructs it purports to measure.[117]
	Responsiveness	The ability of a P-BOM instrument to detect change over time in the construct to be measured.[118]
	Interpretability[119]	The degree to which one can assign qualitative meaning, i.e., clinical or commonly understood connotations, to an instrument's quantitative scores or change in scores.
Clinical utility:	**Precision**	Measurement precision is the consistency of a reported P-BOM score across repeated completions of P-BOMs under the same experimental conditions (Vincent, 1994).
	Acceptability	P-BOMs should also be acceptable (or patient-friendly) to their target population, both in terms of the questions asked (e.g., are they appropriately worded?) and the overall patient burden (e.g., is the completion time for the P-BOM agreeable?). Measures must also be easily interpretable, i.e., the meaning of differences in P-BOM scores should be clearly understood.
	Feasibility	The feasibility (or clinician-friendliness) of instrument administration refers to the time and cost of administration, scoring, and interpretation for clinicians and researchers.
	Appropriateness	The instrument content should be appropriate to the questions the application seeks to address (Vailer and Lam, 2015).

[116] The extent to which scores for patients who have not changed are the same for repeated measurements under several conditions: e.g. using different sets of items from the same P-BOM (internal consistency); over time (test-retest); by different testers on the same occasion (inter-rater); or by the same tester (i.e. raters or responders) on different occasions (intra-rater) (Valier and Kenneth, 2015).

[117] Validity encompasses: **Content validity**, or the degree to which the P-BOM evaluates all important aspects of the disease/disorder; **Construct validity**, whether the behaviour of the measure is consistent with hypotheses regarding: (a) probable relationships with other instruments and/or (b) performance of the tool in different subgroups; and **Criterion validity**, i.e., correlation with a 'gold standard' (Bent et al., 2009).

[118] Responsiveness has been synonymously combined with sensitivity to change in the literature. The sensitivity of a P-BOM to detect change is defined as its ability to detect an actual change in state, regardless of whether the change is relevant or clinically meaningful. Nonetheless, sensitivity to change has been described as insufficient for assessing change and establishing treatment effectiveness (Liang et al., 2002).

[119] Interpretability is not considered a measurement property, but an important characteristic of a measurement instrument (Mokkink et al., 2010).

There are currently many designs and protocols available to measure reliability, although there is little consensus on the optimal method of analysis (Marx et al., 2003; Watson and Petrie, 2010; Hopkins, 2000).

Besides reliability and validity (discussed below), another important psychometric property is the measurement of treatment effect which must be responsive to changes in patients' health over time (Guyatt et al., 1987). This property is often called responsiveness or sensitivity to change in the literature. The sensitivity of an outcome measure to detect change is defined as its ability to detect an actual change in state, regardless of whether the change is relevant or clinically meaningful (Liang, Lew, Stucki, Fortin, and Daltroy, 2002). Nonetheless, sensitivity to change has been described as insufficient for assessing change and establishing treatment effectiveness (Liang et al., 2002). Responsiveness on the other hand, is defined as the ability of an outcome measures to detect meaningful or important changes in a clinical state, and has been advocated as an essential property of outcome measurement to measure change and the effectiveness of interventions (Roach, 2006; Valier and Kenneth, 2015)[120].

Several attempts have been made to objectively evaluate the Performance Profile in terms of the technique's validity and reliability with athletes (Palmer et al., 1996; Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Gleeson et al., 2005). Firstly, results from Doyle and Parfitt (1997) report some support for the construct validity of the Performance Profile, because an increase in actual performance was reflected by a concomitant decrease in Performance Profile areas of perceived needs across the five assessment occasions. The most important qualities of the Performance Profile were more sensitive and responsive to change at certain times within the testing period.

In the only attempt to assess the reliability of the Performance Profile (Gleeson et al., 2005), the day-to-day reproducibility and single measurement of the Performance Profile was examined with athletes. Gleeson and colleagues (2005), within the initial assessment phase, used individual Performance Profiles, where each athlete selected ten to fifteen qualities from an inventory of qualities collectively agreed upon by all the athletes in a previous group discussion. These qualities were attributes that each athlete perceived to be important to an ideal sports-performer in their chosen sport or event. Each athlete's Performance Profile was then reduced to the ten most important qualities for data analysis, determined by the athlete's importance ratings.

A secondary aim of the study by Gleeson et al. (2005) was to investigate the accommodation responses of the Performance Profile. This was achieved by all athletes completing four practice sessions (during an accommodation phase) followed by three consecutive experimental completions

[120] This study refers to both sensitivity and responsiveness to change, these terms have been defined above. Minimal clinically important difference (MCID) is the smallest amount of change a patient perceives as beneficial and is a measure of responsiveness (Beaton et al., 2001). Alongside MCID (further evaluated on p. 166), sensitivity to change has been described as insufficient for assessing change and establishing treatment effectiveness (Liang, 2002), therefore for the purpose of the thesis, the term responsiveness to change will be favoured.

of the same Performance Profile over a three-day period at closely matched times of day, from which the main data was collected. The assessment of four practice attempts during an accommodation phase was to account for the possibility of a learning effect affecting the precision of the profiling (as previously suggested by Doyle and Parfitt (1997)). Following analysis, no significant differences in perceived Performance Profile scores were observed across the accommodation phase, suggesting that four practice profiles were adequate for athletes to adjust and habituate to the Performance Profile. This further implies that any intra-subject changes in Performance Profile scores across the three subsequent data collection points can be attributed to human variability rather than systematic learning effects. Gleeson and colleagues (2005) found that the Performance Profile had a limited capacity to discriminate changes in an athlete's current condition, based on one single assessment of the Performance Profile, and the use of a mean score obtained from a minimum of 10 completions would be required to estimate a performer's current condition to reduce measurement error and enhance the precision of this technique. It would be therefore at times be unsuitable to use this technique with athletes, which reconfirms the rationale for applying the Performance Profile within a clinical setting.

6.2 - Aims and Objectives

The rationale for the use of the Performance Profile in this thesis and within a clinical population is related to fact that the Performance Profile lacks sufficient measurement sensitivity to accurately rate the relatively small changes in performance and self-perceived capability that has been observed with recreational and elite athletes (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Gleeson et al., 2005). It has therefore been recommended that a more suitable application for the Performance Profile would be during post-injury rehabilitation, when significant changes in performance capabilities and perceived needs are more likely (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997; Weston et al., 2013).

The Performance Profile has not yet been investigated in terms of the technique's reliability characteristics and responsiveness to change with ACLD patients following ACLR surgery (Yates et al., 2016), therefore this will be the first aim of this study. Patients are to complete the Performance Profile for five consecutive days within a two-week period prior to ACLR surgery, at a time when they are available to attend pre-surgical assessments with their respective surgeons. This time constraint is imposed with a view to more accurately determining the day-to-day reproducibility and efficacy of the Performance Profile, since it can be assumed that only subtle differences in self-perceived capability would occur as opposed to if the Performance Profile was completed immediately after ACL injury where the day-to-day differences would be substantial.

While the Performance Profile lacks utility in athletic populations, its use among ACL injury patients pre- and post-ACLR surgery experiencing more dramatic changes in their self-perceived capabilities should allow the responsiveness of the Performance Profile to be more effectively evaluated, thus demonstrating its greater utility in a clinical setting (Doyle et al., 1998; Gleeson et al., 2005). The second aim of this study **(Study 3)** will therefore be to apply the Performance Profile pre- and post-ACLR surgery to establish its responsiveness to change.

The third aim of this study **(Study 3)** relates to evaluating the number of items that are used for data analysis in the Performance Profile extracted from the larger number entered by the patient. For the purposes of data analysis, in the majority of Performance Profiling literature, athletes' profiles are generally reduced to the ten or twenty most important items, yet it is not yet known whether the number of items (constructs) used in the analysis has any impact on the reliability of their Performance Profiles. It is evident, however, that if the Performance Profile is found to be equally reliable when only five items are analysed as opposed to ten or more, this would have pragmatic benefits for patients and clinicians alike in terms of the time taken to create, complete and evaluate patient profiles, making it a more efficient tool for use in clinical practice. Therefore, **(Study 3)** will assess whether the first five most important self-perceived needs as identified by the patient, more accurately determine reliability compared to an analysis incorporating the ten or fifteen most important needs evaluated over five repeated administrations. This aspect of the study will be evaluated within the context of aims 1 and 2.

The final aim of this study **(Study 3)** relates to the clinical utility of the Performance Profile discussing aspects of acceptability, feasibility and appropriateness (Aim 4). By ascertaining the time taken to enter items into the Performance Profile and rate them by order of importance it will be possible to assess its clinical utility in relation to more traditional methods used in clinical practice. The study will examine whether the technique can easily be incorporated into routine patient care with no adverse impacts on the clinician's normal workflow, and whether it provides an effective means of achieving the healthcare objectives of both patient and clinician.

TABLE 49 - Study 3 aims and objectives.

CHAPTER 6	**Aims and Objectives**
Study 3 Reliability investigation	The Performance Profile has yet to be investigated in terms of the technique's reliability characteristics and responsiveness to change with symptomatic ACLD and ACLR patients, therefore, the aims of this study are: **(1)** To determine the day-to-day reproducibility and efficacy of the Performance Profile two weeks pre-ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over five days. **(2)** To examine the responsiveness of the Performance Profile's administration one day prior to ACLR surgery compared to one day post-ACLR surgery. **(3)** To assess whether reducing the data analysis to the patient's top five most important self-perceived needs, produces outcomes that are of equal reliability compared to a broader analysis incorporating the first ten or fifteen most important needs evaluated over five repeated administrations, within the context of aims 1 and 2. **(4)** To ascertain the time taken to enter items in the Performance Profile and complete the importance ratings for each item, with a view to establishing the clinical utility of the technique compared to more traditional methods used in clinical practice.

6.3 - Methods

Parts of this methodology section have been truncated; the assessment procedure and protocols deployed throughout this study have been provided - where indicated please refer to general methods section (see p. 162) for full descriptions of specific methodologies. All data was collected within a two-week period prior to each patient's ACLR surgery.

6.3.1 - Participants

Forty-one patients (30 male [age at surgery (years): 28.5 ± 11.9 (range 16.6 to 40.4); height (cm): 173.7 ± 9.1; body mass (kg): 75.5 ± 9.1]; 11 females [age at surgery (years): 31.3 ± 13.7 (range 17.6 to 45); height (cm): 160.1 ± 4.3; body mass (kg): 62.2 ± 9.9]),]; [mean ± SD]), electing to undergo unilateral ACLR surgery (central third, bone-patella tendon-bone graft [n=3], or semitendinosus and gracilis graft [n=38]) at Robert Jones and Agnes Hunt Orthopaedic and District Hospital (NHS Foundation Trust hospital), Oswestry (UK), gave their informed consent to participate in the study. All information that was collected during the course of the research was kept strictly confidential, and the rights of all participants were protected.

Participants were selected from a cohort of patients presenting with arthroscopically-verified unilateral complete ACL rupture at the hospital over a six-month period. Patients meeting inclusion and exclusion criteria (p. 161) were eligible for this study and were offered participation. In brief, no exclusions were made on the basis of gender or race, and patients over 16 years old who were deemed musculoskeletally and mentally mature were invited to participate. All participants received ACLR surgery on average 164.9 ± 87.4 (range: 77-249) days following ACL injury. Participants were not given feedback of results until after the study was completed.

TABLE 50 - Patient anthropometric and clinically-related characteristics for Study 3.

	Patient characteristics	
	Male (n = 30)	Female (n = 11)
Age at surgery (years):	28.5 ± 11.9	31.3 ± 13.7
Height (cm):	173.7 ± 9.1	160.1 ± 4.3
Body mass (kg):	75.5 ± 9.1	62.2 ± 9.9
Time from injury to surgery (days):	164.9 ± 87.4	172.3 ± 118.9

6.3.2 - Study design and procedure

Once accepted into the study, each participant was introduced to the study's procedures, indicating their involvement within the study prior to the collection of Performance Profiling data. Prior to eliciting an individualised Performance Profile, and as suggested by Weston (2008), each participant was introduced to the Performance Profile procedure at least 4 weeks before their first assessment occasion via personal communication, usually during a patient consultation with the orthopaedic surgeon. This allowed sufficient time for each participant to review and generate a list of potential physical self-perceived needs that he or she felt were important to be resolved to achieve full recovery following ACL injury. Each participant was asked to consider the following question, "What, in your opinion are the 'elements' of your knee in 'need' of physical rehabilitation or the 'elements' to be improved upon to obtain full recovery?" A list of self-perceived (physical) needs were recorded, and all participants were asked to consider this question at home until the study's commencement two weeks prior to each patient's ACLR surgery.

Subsequently, within a two-week period prior to each participant's ACLR surgery, each participant was asked again to consider the above question to elicit an individualised Performance Profile. In brief, the original protocols and procedures described by Butler and Hardy (1992) were applied during an individual consultation with the author of this thesis (p. 178). The same research team member delivered this introduction and elicitation stage of perceived needs to all participants to ensure consistency of the profiling procedure. Once an inventory of profiling items had been identified by each participant, which had acknowledged a list of self-perceived needs, participants were required to perform a self-assessment on their 'injured' limb for each of the identified perceived physical needs. Participants were asked: "how are you feeling at the present time on each of the 'elements' you have listed?" Participants used the response scale to answer this question, which ranged from [0] 'my knee feels far from recovered' to [10] 'my knee feels fully recovered'. The same self-assessment procedure was conducted for the 'non-injured' contralateral limb. Participants recorded their responses by shading the area which corresponded to the response scale.

In addition, each participant was required to determine the relative importance of each item within their profile, as with previous research (Weston et al., 2011b), by asking the patient to consider the question, "how important are each of the 'elements' you have listed?" Participants used a response scale which ranged from, 'of crucial importance' to 'not important at all'. For example, if a participant elicited a Performance Profile chart with twenty items, they would rate them in order of importance from one to twenty. However, if a participant elicited only twelve items, this patient would only be able to rank their importance from one to twelve.

At this initial assessment occasion (P1), each participant's Performance Profile was reduced to the fifteen most important items for data analysis, and these would remain constant across all the assessment occasions (P1, P2, P3, P4, P5, and P6), so that patients repeatedly rated the same items on each of the assessment occasions. The first Performance Profile (P1) was completed together with the research team to ensure each participant was comfortable with the profiling procedures and methodology of the technique.

At present, there is no evidence available to help decide on the time interval between questionnaire administrations for a study of the test-retest reliability of health status instruments or performance profiles. With this said, chosen test-retest intervals generally range from 1 day to 2 weeks (Marx et al., 2003). Previous Performance Profile research evaluating test-retest of profiles have deployed serial profile completions within a three-day period (i.e., first profile completion was at 10:00 am on the first day; the second was 1 hour later (11:00 am) on the same day, and the third was at 10:00 am, 2 days later) (Gleeson et al., 2005). Further, as discussed by Paiva et al. (2014), with relation to the evaluation of outcomes within clinical environments, it was suggested that confirming clinical stability before re-testing patients is more important than the time interval itself (Paiva et al., 2014). Considering all of the above, allowing a 24-hour period between serial completions was thought to minimise the interference of potential recall of previous profile responses (Frost et al., 2007).

Subsequently, each participant was required to complete three additional Performance Profiles at home over a three-day period at closely matched times of the day (P2, P3, and P4, respectively)[121]. It was important that when each participant completed their subsequent three Performance Profile at home, and that the previously completed Performance Profile was not examined. To ensure this, each participant was given three envelopes in which to place their completed Performance Profiles. The envelopes were to be sealed so they could not be accessed during completion of the next Performance Profiles.

Each participant completed an additional Performance Profile the day before ACLR surgery (denoted as P5) and one day following surgery (denoted as P6). The principal researcher, the author of this thesis, was present for both completions. The Performance Profiling protocol is represented schematically in **FIGURE 31**.

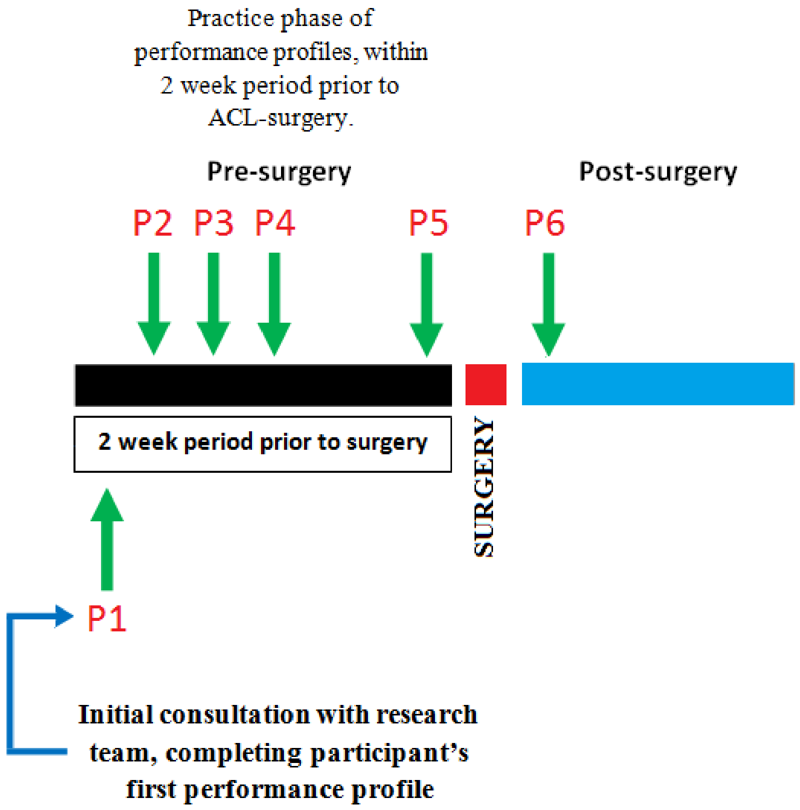

FIGURE 31 - Protocols for Study 3

[121] The completion of five consecutive Performance Profiles conducted within a two-week period prior to ACLR surgery will be referred to as the accommodation phase, and is referred to as practice sessions, denoted, P1, P2, P3, P4 and P5 respectively.

6.4 - Statistical analyses

The software that was utilised for the statistical analysis for the study 3 was Statistical Package for Social Sciences (SPSS; version. 20.0). All descriptive statistics (mean and standard deviation) are presented where appropriate. A minimum of 50 participants is a general recommendation for reproducibility studies (Altman, 1991). It was anticipated that over the data collection period, and the number of ACL surgeries performed per month, this number or more would be easily obtained. Sixty-one patients were initially recruited for this study, however, participants reporting less than fifteen items (n = 20) and patients not completing all assessment occasions (n = 3) were removed from data analysis. Therefore, statistical analyses were performed on a total of forty-one participants in this study.

6.4.1 - The day-to-day reproducibility of the Performance Profile two weeks pre-ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over five days

A group mean Performance Profile score for all profile items on each participant's Performance Profiles were compared across all five assessment occasions (P1, P2, P3, P4, and P5) prior to each patient's ACLR surgery using a one-way repeated measures analysis of variance (ANOVA). This procedure was used to check for systematic learning effects across trials within each assessment session (intra-day) to identify whether or not this Performance Profiling practice period of five assessment occasions was sufficient for participants to have adjusted to the technique. Under such circumstances, subsequent Performance Profile ratings would be influenced only by random physiologic variability rather than by evidence of systematic residual effects between test occasions, such as learning (Frost et al., 2007; Batterham and George, 2003).

Single-measurement reliability was assessed by computing an Intra-class Correlation coefficient (ICC) (2,1 model) and a Standard Error of Single Measurement (SEM %) (95% confidence limits), expressed as a percentage of the group mean score according to the formula ((SD x √ (1- RI)) / mean) • 100 (multiplied by 1.96 to compute 95% confidence limits and assuming a normal distribution of scores). The ICC were calculated to assess the consistency and average agreement across five assessment occasions (P1, P2, P3, P4, and P5) in the fifteen most important Performance Profile items. The ICC determines the degree of correspondence and agreement across the five ratings and is therefore preferable to Pearson's correlation coefficient which can only assess bivariate relationships between two items at one time (Portney and Watkins, 2000). Values for the ICC range from 0 to 1 with higher values above 0.75 indicating good reliability. Values above 0.90 indicate excellent reliability and are preferred for high quality standardised measures (Portney and Watkins, 2000).

Internal consistency of each of the Performance Profile versions (5 items, 10 items, and 15 items) was additionally assessed using Cronbach's alpha (a), in both the injured and non-injured limbs, to measure the internal consistency of the items within each Performance Profile version. Internal consistency measures the correlation among all items within a particular scale. Cronbach's alpha values have a possible range from 0 to 1, with preferred values in the range of 0.70, which indicates acceptable internal consistency to 0.90 (Portney and Watkins, 2000). Nunnally (1978) recommended that a 0.70 value should be a cut-off, however, here 0.80 is the preferred minimum threshold.

The use of coefficient of variation (CV %) is a commonly used method of measuring the acute variability associated with repeated assessments of outcome measures by the same individual (Gleeson, 1996)[122]. CV% was corrected for small sample bias (Sokal and Rohlf, 1994) and was used to assess variability of Performance Profile variables across all assessment occasions for each intra-day session. The latter index was calculated according to the expression (SD/mean) • (1 + (1/4n) • 100) and expressed as a percentage, where n is the number of trials.

6.4.2 - To examine the responsiveness of the Performance Profile's administration one day prior to ACLR surgery compared to one day post-ACLR surgery

Following the four serial completions of the Performance Profile (P1, P2, P3, and P4), each participant completed a Performance Profile the day before ACLR surgery and again the day following surgery (P5 and P6, respectively). It was expected that profile scores would be largely different due to the invasive knee surgery. The purpose of these two completions of the Performance Profile over this period (pre- and post-ACLR surgery) was to examine its responsiveness. The comparison of the means of the Performance Profile for all the practice completions (P1, P2, P3, P4, and P5) prior to ACLR surgery were calculated and compared to the mean Performance Profile scores post-ACLR surgery (i.e., [P1, P2, P3, P4, and P5] versus [P6]) and discussed descriptively. In addition, the mean Performance Profile scores for each three versions of the Performance Profile (5 items, 10 items, and 15 items) were also compared across the five assessment occasions (P1, P2, P3, P4, and P5) using a 2-factor ANOVA and evaluated against the mean Performance Profile score following ACLR surgery (P6). This statistical procedure was calculated for both the injured and non-injured limbs.

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[122] The coefficient of variation (CV) is the ratio of the standard deviation to the mean. The higher the coefficient of variation, the greater the level of dispersion around the mean. It is generally expressed as a percentage. Without units, it allows for comparison between distributions of values whose scales of measurement are not comparable (Lexell and Downham, 2005).

6.4.3 - To assess whether reducing the data analysis to the patient's top five most important self-perceived needs, produces outcomes that are of equal reliability compared to a broader analysis incorporating the first ten or fifteen most important needs evaluated over five repeated administrations

In the majority of Performance Profiling literature, athlete's profiles are generally reduced to the ten or twenty most important items, yet it is not yet known whether the number of items (constructs) used in the analysis has any impact on the reliability of their Performance Profiles. Therefore, it was important to assess whether the first five most important self-perceived needs as identified by the patient more accurately determine reliability compared to an analysis incorporating the ten or fifteen most important needs evaluated over five repeated administrations. The comparison of the three Performance Profile versions (5 items, 10 items, and 15 items) were evaluated within the other aims of the study, as discussed above, for the injured and non-injured limbs.

6.4.4 - To ascertain the time taken to enter items in the Performance Profile and complete the importance ratings for each item, with a view to establishing the clinical utility of the technique compared to more traditional methods used in clinical practice

Pilot testing of the Performance Profile (not shown in thesis) reported that familiarisation with the profiling procedure in terms of understanding the concepts and constructing suitable lists of perceived physical needs was assumed to be the most time-consuming constraint. To quantify this, the time taken to introduce the outlined Performance Profiling procedures (Butler and Hardy, 1992), and the time taken to generate a final list of self-perceived needs to elicit an individualised Performance Profile were recorded. In addition, the time involved in the self-assessment stages, when each participant was required to report a response measure for each self-perceived need constructed in their Performance Profile and then prioritise each perceived need by order importance was also determined (see Weston et al., 2011b). Within each of these two stages, the time taken to complete each stage was recorded by the author of the thesis, at P1, P5, and P6. The remaining assessment occasions (P2, P3, and P4) were completed at home and the time taken to complete the respective Performance Profiles was documented by each patient.

6.5 - Results

6.5.1 - To determine the day-to-day reproducibility and efficacy of the Performance Profile two weeks pre-ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over five days (P1, P2, P3, P4, and P5)

Group means (and SD) for all Performance Profile versions (5 items, 10 items, and 15 items) were calculated for all assessment occasions across the experimental period (P1, P2, P3, P4, P5, and P6) and can been seen in **TABLE 51** and **FIGURE 32**. The Performance Profile mean scores across the five assessment occasions pre-ACLR surgery (P1, P2, P3, P4, and P5) were compared using a single-factor repeated measure analysis of variance (ANOVA). A single-factor ANOVA with repeated measures suggested that no significant systematic learning occurred across the five assessment occasions (P1, P2, P3, P4, and P5) for both injured and non-injured limbs. This finding suggests that the completion of five Performance Profiles within a two-week period prior to ACLR surgery was adequate for patients to adjust and habituate to the Performance Profile and associated procedures, and as such, further supports that the intra-subject changes in Performance Profile scores across the subsequent data collection points can be attributed to human variability rather than to systematic learning effects.

TABLE 51 - Group mean scores for Performance Profile (intra-day) [mean ± SD] assessment sessions for injured and non-injured limbs at pre-surgery (P1, P2, P3, P4, P5) and at post-surgery assessment (P6) of patients with unilateral ACL injury.

	Performance Profile (Mean ± SD)					
	5 items		**10 items**		**15 items**	
Assessment occasion	**Injured**	**Non-injured**	**Injured**	**Non-injured**	**Injured**	**Non-injured**
P1	5.7 ± 1.6	9.6 ± 0.5	5.7 ± 1.5	9.6 ± 0.5	5.9 ± 1.4	9.7 ± 0.4
P2	5.8 ± 1.5	9.7 ± 0.4	5.6 ± 1.5	9.6 ± 0.5	5.7 ± 1.5	9.7 ± 0.4
P3	6.1 ± 1.6	9.6 ± 0.5	5.9 ± 1.6	9.6 ± 0.5	5.9 ± 1.6	9.6 ± 0.5
P4	5.9 ± 1.7	9.6 ± 0.5	5.7 ± 1.6	9.6 ± 0.5	5.8 ± 1.6	9.7 ± 0.5
P5	5.6 ± 1.6	9.6 ± 0.5	5.4 ± 1.6	9.6 ± 0.6	5.6 ± 1.6	9.6 ± 0.6
P6	2.3 ± 1.1	9.5 ± 0.7	2.4 ± 1.0	9.6 ± 0.7	2.5 ± 1.0	9.5 ± 0.7

The internal consistencies of all the Performance Profile versions were identical for the injured limb (α= 0.96), indicating that each version demonstrated excellent internal consistency < 0.90[123]. The Cronbach's alpha analysis of all the Performance Profile versions also reported excellent reliability for the non-injured leg ranging from 0.97 to 0.98. Intra-class correlation (ICC) coefficient scores ranged from 0.95 to 0.96, for the injured leg, and from 0.97 to 0.98 for the non-injured leg, indicating the high reliability of the five assessment occasions (P1, P2, P3, P4, and P5) in each Performance Profile version examined. Overall, the above results suggest that the

[123] ICC (1, 2 model) was used.

Performance Profile reduced to a 5-item inventory produced similarly high levels of reliability compared to versions using 10 or 15 items. Despite this, it was decided that a 10-item inventory would be more useful for the purpose of this thesis in order to more effectively assess and understand patients' self-perceived physical needs.

Pearson product-moment correlations were performed to assess the concurrent validity of all the Performance Profile versions (5 items, 10 items, and 15 items), separately for the injured leg **(TABLE 54)** and non-injured leg **(TABLE 55)**. All of these correlations were significant at a probability level of $p<0.01$ level, with strong effect sizes ($r> 0.80$). These results indicate excellent concurrent validity of the Performance Profile versions.

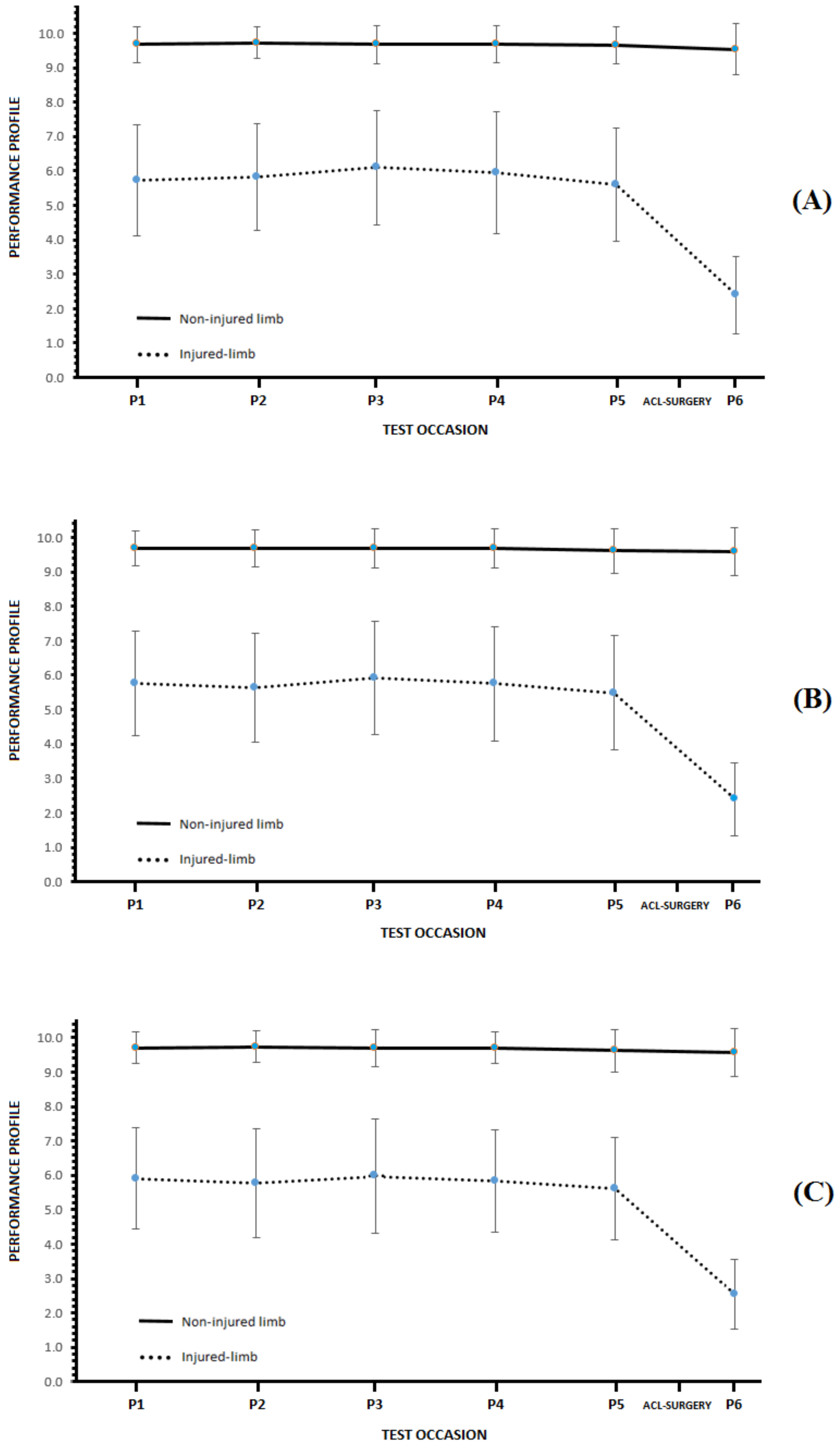

FIGURE 32 - Group mean Performance Profile scores (Mean ± SD) for the injured and non-injured limbs at pre-surgery (P1, P2, P3, P4, and P5) and post-ACLR surgery assessment occasions (P6), evaluated with three Performance Profile versions [(a) 5 items, (b) 10 items, (c) 15 items] with patients with unilateral ACL injury.

TABLE 52 - Cronbach's alpha [α]) and Intra-Class Correlation (ICC) coefficient scores for injured and non-injured limbs across five mean scores (P1, P2, P3, P4, P5) in each of the three versions.

	Cronbach's alpha [α]		**ICC, average measure**	
	Injured	Non-injured	Injured	Non-injured
5 items	0.96	0.98	0.95	0.98
10 items	0.96	0.98	0.96	0.98
15 items	0.96	0.97	0.96	0.97

The use of Coefficient of Variation (CV %) is a commonly used method of measuring the acute variability associated with repeated test occasions of outcome measures by the same individual (Gleeson et al., 1996).

TABLE 53 show the intra-day group mean coefficient of variation (CV %) scores for the Performance Profile versions for injured and non-injured limbs at pre-ACLR surgery (P1, P2, P3, P4, and P5).

TABLE 53 - Intra-day group mean coefficient of variation (CV %) [MEAN ± SD] for Performance Profile assessment occasions for injured and non-injured limb pre-surgery (P1, P2, P3, P4, and P5) in patients with unilateral ACL injury.

	Coefficient of variation (CV %)	
	Injured	**Non-injured**
5 items	11.3 ± 7.6	1.1 ± 1.6
10 items	10.1 ± 7.4	1.0 ± 1.7
15 items	9.7 ± 7.5	0.9 ± 1.7

TABLE 54 -Inter-correlations amongst Performance Profile versions (5 items, 10 items, and 15 items) in the injured limb.

	Performance Profile (inter-correlation, r)[124]		
	5 items	**10 items**	**15 items**
5 items	-	.899⁞	.837⁞
10 items		-	.930⁞
15 items			-

TABLE 55 -Inter-correlations amongst Performance Profile versions (5 items, 10 items, and 15 items) in the non-injured limb.

	Performance Profile (inter-correlation, r)[125]		
	5 items	**10 items**	**15 items**
5 items	-	.859⁞	.858⁞
10 items		-	.973⁞
15 items			-

6.5.2 - To examine the responsiveness of the Performance Profile's administration one day prior to ACLR surgery compared to one day post-ACLR surgery.

A one-way repeated measures analysis of variance (ANOVA) reported that no significant systematic learning trends were observed across the five assessment occasions (P1, P2, P3, P4, and P5) ($F_{(40,4)} = 1.9$, *ns*). Therefore, group pooled Performance Profile means scores were calculated (i.e., P1 + P2 + P3 + P4 + P5) and evaluated to mean Performance Profile scores at P6 post-ACLR surgery. The analysis pre- and post-ACLR surgery was intended to investigate the Performance

[124] ⁞ Correlation is significant at the 0.001 level (2-tailed).
[125] ⁞ Correlation is significant at the 0.001 level (2-tailed).

Profile's ability to detect change during this period of dramatic change that would be expected during ACLR (Doyle et al., 1998).

TABLE 56 shows group pooled mean scores for all pre-surgery Performance Profiling assessment occasions (i.e., P1 + P2 + P3 + P4 + P5) compared against group mean Performance Profile scores assessed one day post-ACLR surgery (P6) for injured and non-injured limbs of patients with unilateral ACL injury. Over the experimental period, mean Performance Profile scores for the non-injured leg were maintained throughout all assessment occasions' pre- and post-ACLR surgery. The mean Performance Profile scores in the injured leg were significantly less post-ACLR surgery compared to pre-surgery assessment occasions. Descriptively, the mean Performance Profile scores showed a 57.7% decrease in the injured leg from pre-surgery assessment occasions to post-ACLR surgery assessment occasions. Following ACLR surgery, participants perceived a 3.34-unit reduction (Performance Profile [maximum score of 10]) for the injured limb, while only a 0.13-unit change was observed (1.3% change from surgery) for the non-injured limb. This reduction in self-perceived capability for the injured limb in comparison to the non-injured limb provides evidence of the responsiveness of the Performance Profile to detect change **(FIGURE 33).**

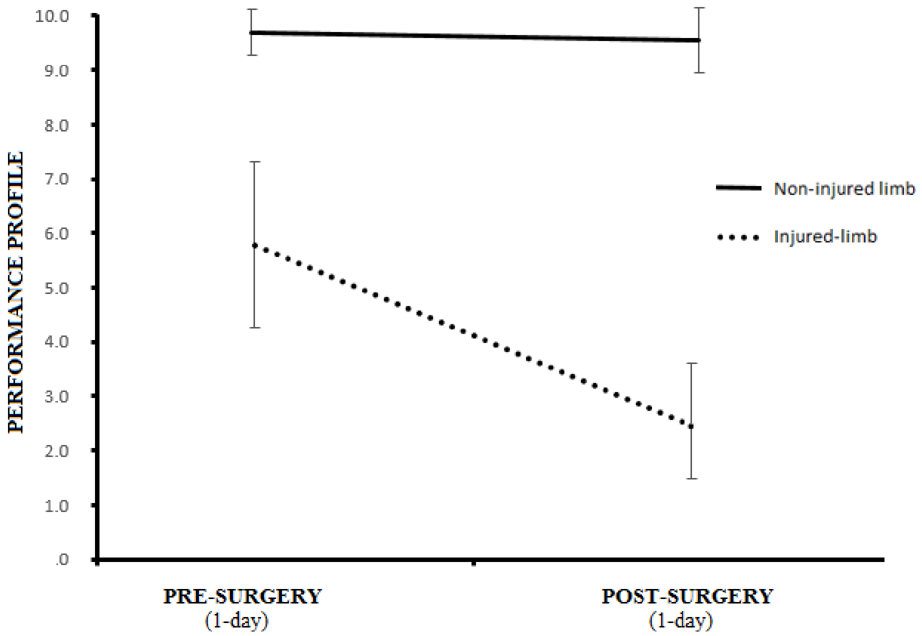

FIGURE 33 - Group pooled means for all Performance Profile scores pre-surgery (P1+P2+P3+P4+P5) versus post-surgery mean Performance Profile scores (P6) for injured and non-injured limbs with unilateral ACL injury (Mean ± SD).

TABLE 56 - Group mean Performance Profile scores for three profile versions (5 items, 10 items, and 15 items) pre- (pooled means: P1, P2, P3, P4, and P5) and post-ACLR (P6) surgery for injured and non-injured limbs.

	Performance Profile (Mean ± SD)					
	5 items		10 items		15 items	
Assessment occasion	**Injured**	**Non-injured**	**Injured**	**Non-injured**	**Injured**	**Non-injured**
Pre-surgery (pooled means)	5.8 ± 1.5	9.6 ± 0.5	5.7 ± 1.5	9.6 ± 0.5	5.8 ± 1.5	9.6 ± 0.4
Post-ACLR surgery (P6)	2.3 ± 1.1	9.5 ± 0.7	2.4 ± 1.0	9.5 ± 0.7	2.5 ± 1.0	9.5 ± 0.7

6.5.3 - To ascertain the time taken to enter items in the Performance Profile and complete the importance ratings for each item, with a view to establishing the clinical utility of the technique compared to more traditional methods used in clinical practice

At the first assessment occasion (P1), all patients were introduced to the Performance Profiling and followed Butler and Hardy's (1992) individual consultation procedure. Following the introduction and elicitation process to formulate an individual profile, all patients completed this procedure within 6.32 to 12.52 minutes **(TABLE 57)**. Once this first stage of Butler and Hardy's (1992) procedure had been achieved, each patient was required to evaluate each individual item and to score them accordingly. In this self-assessment stage, participants entered their profile items evaluated in 6 separate completions within 1.12 to 3.48 minutes. Similarly, the relative importance of the profile items across the same assessment occasions were rated within 50 seconds to 3.20 minutes. Overall, the total time spent in the self-assessment stages (as above), completing both the responses and relative importance of each profiling item was 2.02 to 7.08 minutes.

TABLE 57 - Timings (minutes and seconds) to complete performance profiling procedures/stages ([1] introduction of the profiling procedure to each participant and elicitation of self-perceived physical needs following injury and [2] determination of self-assessment responses of individual items (constructs) and relative importance rating of the items (constructs)) for participants over six assessment sessions (Mean and SD).

	Introduction and elicitation	Self-assessment stages: (1) and (2) (Mean ± SD)		
	Total time	(1) Responses to individual items	(2) Rating of relative importance of items	**Total time**
Practice 1	9.42 ± 3.10	2:58 ± 1:04	2:04 ± 1:21	5:02 ± 2:25
Practice 2		2:55 ± 1:55	2:00 ± 1:38	4:55 ± 3:33
Practice 3		2:21 ± 1:18	2:10 ± 1:11	4:31 ± 2:29
Practice 4		2:07 ± 1:01	2:15 ± 1:06	4:22 ± 2:07
Practice 5		2:04 ± 1:05	1:59 ± 1:06	4:03 ± 2:11
Practice 6		2:34 ± 1:23	2:01 ± 1:07	4:35 ± 2:30
TOTAL	**9.42 ± 3.10**	**2:30 ± 1:18**	**2:05 ± 1:15**	**4:35 ± 2:33**

6.6 - Discussion

This study represents the first attempt to assess the day-to-day reproducibility and efficacy of the Performance Profile within two weeks prior to ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over five days. All participants elicited an individualised Performance Profile which represented their self-perceived physical needs which patients rated from least to most important to obtaining full recovery following ACL injury. Secondary objectives of the study were to evaluate the Performance Profile pre- and post-ACLR surgery to establish its responsiveness to change (Aim 2), and to assess whether the first five items within each patient's Performance Profile rated as most important do more accurately determine reliability compared to the first ten or fifteen items rated as most important over five repeated completions (Aim 3)[126]. Each of the presented aims will be critically evaluated separately.

[126] Study 3 **(Chapter 6: Reliability investigation)** and Study 4 **(Chapter 7: Intervention RCT investigation)** both evaluated patients' perceived physical needs (i.e., pain, strength, range of motion, instability, giving way, etc.), by the participant being asked to consider the following question, "What, in your opinion are the

A concern with testing reliability by the test-retest method is that there is a potential for learning, carry-over, or recall effects (Frost et al., 2007), and when establishing a new measurement technique, both the measurement variability and measurement error must be taken into consideration (Watson and Petrie, 2010). Considering all of these constraints, it was important to habituate participants to the Performance Profiling procedures within an accommodation phase[127] to control for potential learning effects, since only then can the accurate assessment of reliability be performed (Batterham and George, 2003). It was anticipated there would only be subtle differences in self-perceived capability at two weeks pre-ACLR surgery as opposed to if the Performance Profile was investigated immediately after ACL injury when the day-to-day differences would be substantial. A further concern was the logistical considering of how to capture a large number of participants, with a minimum of 50 participants generally being recommended (Altman, 1991), and how best to evaluate all patients within a similar timeframe. Most patients in this study attended pre-surgical assessments with their respective surgeons within a period close to ACLR surgery. Therefore, serial completions of Performance Profiles were collected within two weeks prior to ACLR surgery, when it is assumed patients would likely only demonstrate subtle differences in self-perceived capability. This seemed the most suitable and convenient place to evaluate the Performance Profile's day-to-day reproducibility and the efficacy of this technique.

Previously, Performance Profile literature has acknowledged that this profiling technique lacks measurement sensitivity with athletes (Doyle and Parfitt, 1996; Doyle and Parfitt, 1997, Gleeson et al., 2008), and the evaluation of the Performance Profile within a clinical setting would allow patients further discrimination of self-perception of capability. It was further of interest to evaluate the Performance Profile pre- and post-ACLR surgery, as it would be expected that this period of dramatic change would provide a much larger discrepancy in self-perception capability due to ACLR surgery. Within this period, pre- and post-ACLR surgery, the measurement of this effect should be responsive to change and would provide an opportunity to evaluate the responsiveness of the Performance Profile, which may further endorse its greater utility in a clinical setting (Doyle et al., 1998; Gleeson et al., 2005).

The third aim of this study relates to evaluating the number of items used for data analysis in the Performance Profile from those selected by the patient. Therefore, it was necessary to assess whether the first five most important self-perceived needs as identified by the patient more accurately determine reliability compared to the first ten or fifteen evaluated over five repeated administrations.

'elements' of your knee in 'need' of physical rehabilitation or the 'elements' to be improved upon to obtain full recovery?"

[127] The assessment of 5 administration attempts within an accommodation phase (pre-surgery) was to account for the possibility of a learning effect intruding on the precision of the profiling (as previously recommended by Doyle and Parfitt, 1997).

6.6.1 - The day-to-day reproducibility and efficacy of the Performance Profile two weeks pre-ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over five days

A separate one-way analysis of variance (ANOVA) with repeated measures revealed no significant differences in five consecutive administrations of the Performance Profile for injured and non-injured limbs within a two-week period prior to ACLR surgery. Thus, the outcome of this study firstly suggests that the completion of one Performance Profile (at P1) meant that each patient adjusted to the technique's procedures and the intra-subject changes in Performance Profile scores over the remaining assessment occasions (P2, P3, P4, P5) were attributable to human variability of day-to-day changes rather than any systematic learning effects associated with the Performance Profiling procedures. Although, the Performance Profile was deployed prior to ACLR surgery (during an accommodation phase) within a relatively controlled population, the reliability and day-to-day reproducibility of the Performance Profile was collected through a 24-week period of rehabilitation (not discussed in this thesis). Therefore, this accommodation period (i.e., the 2-week period prior to ACLR surgery) could be described as a period of clinical stability before retesting patients throughout their 24 weeks of rehabilitation (Paiva et al., 2014). Further research would be required to investigate systematic (potentially much more likely over 6-weeks) versus random variability in measurements assessed over 24 hours to check for systematic carry-over effects, such as learning.

The findings from Cronbach's alpha and ICC analyses suggest that the injured and non-injured limbs over five consecutive assessment occasions (P1, P2, P3, P4, and P5), evaluated by Performance Profile mean scores, all demonstrated very high levels of reliability (< 0.90). Cronbach's alpha [α] scored 0.96 for the injured leg, and from 0.97 to 0.98 for the non-injured leg, indicating high reliability over all assessment occasions (P1, P2, P3, P4, and P5) in each of the three versions of the Performance Profile (5 items, 10 items and 15 items). Similarly, Intra-Class Correlation (ICC) coefficient scores ranged from 0.95 to 0.96 for the injured leg, and from 0.97 to 0.98 for the non-injured leg, indicating high reliability across the same assessment occasions (P1, P2, P3, P4, and P5) in each of the three versions of the Performance Profile. The outcome of these results (Cronbach's alpha and ICC) suggests that the Performance Profile evaluated by all three versions assessed for the respective limbs, had very high reliability.

The above obtained results were evaluated from the self-assessment stage, which involved each patient scoring a response to individual items within his or her Performance Profile, for the injured and non-injured limb, within two weeks prior to ACLR surgery, through analysis of a series of Performance Profiles completed consecutively by patients over 5 days. Within the same self-assessment stage, each patient rated each profile item from least to most important to achieving full recovery following ACL injury. The rating of the relative importance of the items was not evaluated in this study, but it could be a potential future avenue for research to determine that, within a relatively controlled setting, patients could reliably identify the most important profile items.

The first Performance Profile (P1) was completed with the author of this thesis to ensure each participant was comfortable with the profiling procedures and methodology. Due to the logistical issues of patients attending within a two-week period prior to surgery at different times of the working day, it was not possible to confine all patient to complete all Performance Profiles at the same time, due to the clinical demands. Ideally, the remaining Performance Profiles (P2, P2, and P3) should have been completed at the assessment and physiotherapy centre, but with many patients living some distance from the hospital, and the logistical issues and time constraints involved in having patients re-attend in the following days to complete the subsequent performance profiles, patients completed them at home. Each participant was given three envelopes in which to place their Performance Profiles once completed. This method of concealment was not ideal, but was a means of reducing the chance of patients seeing previously completed profiles. Further research would therefore be required to complete all serial completions under the supervision of the research team at the same time of day, and to ensure that no previous Performance Profile was examined.

At present, there is limited evidence available to help determine the time interval between questionnaire administrations for a study of test-retest reliability for health status instruments, or the Performance profile. Nonetheless, chosen test-retest intervals generally range from 1 day to 2 weeks (Marx et al., 2003). Previous Performance Profile research evaluating test-retest of profiles have deployed serial profile completions within a three-day period (i.e., first profile completion was at 10:00 am on the first day, the second was 1 hour later (11:00 am) on the same day, and the third was at 10:00 am, 2 days later) (Gleeson et al., 2005), though with recreational athletes without concerns. With this study design, a twenty-four-hour period between serial completions was deemed appropriate to minimise interference from potential recall of previous profile responses (Frost et al., 2007). However, future research would be useful to evaluate the test re-test of Performance Profile within extended intervals (i.e., 3-4 days or longer) to re-confirm the reliability characteristics.

In summary, this study has shown that the Performance Profile has demonstrated suitable psychometric properties in terms of its reliability, evaluated pre-surgery, as an outcome measure that can be included in a clinical controlled RCT to assess patients' self-perceived needs **(Study 4: Chapter 7)**. Future research would be required to examine the reliability characteristics of the Performance Profile post-ACLR surgery. More specifically, within a 24-week post-ACLR rehabilitation programme. It would also be useful to investigate other psychometric assessment capabilities (validity, ability to detect change, and interpretability, i.e., minimum important difference) of the Performance Profile to further substantiate the Performance Profile's practical application within clinical practice.

6.6.2 - To examine the responsiveness of the Performance Profile's administration one day prior to ACLR surgery compared to one day post-ACLR surgery.

A subsidiary aim was to examine the responsiveness of the Performance Profile completions pre-surgery (one-day prior) versus post-ACLR surgery (one day following). As expected, the group mean Performance Profile scores of 10 items in the injured limb was descriptively reported less than post-ACLR surgery compared to pre-surgery assessment occasions accounting for a 57.7% decrease in knee performance. The non-injured limb within the same period remained relatively unchanged. More specifically, post-ACLR surgery, patients perceived a 3.34-unit reduction for the injured limb whilst only a 0.13-unit reduction was observed (1.3% change from surgery) in the non-injured limb. The reduction in self-perceived capability for the injured limb compared to the non-injured limb provides the first support for the responsiveness of the Performance Profile to detect changes following ACLR surgery. When evaluating the responsiveness of the Performance Profile, it would also be important to address the associated ceiling effects which may impact the instrument's validity (Valier and Kenneth, 2015). Ceiling effects occur when a percentage of the Performance Profile scores are at the highest level of health, even when suffering from a health condition, such as an ACL injury (Fitzpatrick et al., 1998).

In addition, the novelty of this study was the inclusion of the contralateral limb (non-injured limb) as a way to evaluate change compared to the injured leg. Although some physiological de-conditioning of this control leg's capabilities was likely to have occurred, due to altered physiological loading in the period between ACL injury and ACLR, it nevertheless represented a best estimate of a reference (baseline) performance capability (Gleeson et al., 2008). Overall, the rating of the Performance Profile of the non-injured limb remained constant at pre-surgery, and following ACLR surgery, with a non-significant difference between injured and non-injured limbs pre- and post ACLR surgery, suggesting that the non-injured leg scores by the Performance Profile were affected by ACLR surgery.

6.6.3 - To assess whether reducing the data analysis to the patient's top five most important self-perceived needs, produces outcomes that are of equal reliability compared to a broader analysis incorporating the first ten or fifteen most important needs evaluated, over five repeated administrations within the context of aims 1 and 2.

Overall, the outcome of the study suggests that the Performance Profile can be reduced to a 5-item inventory as it produced similarly high levels of reliability compared to versions using 10 or 15 items. In this respect, it was prudent to assume that patients' Performance Profiles could be reduced to the ten most important items for data analysis. In a practical sense, using either 5 or 10 items should make deployment of the Performance Profile in clinical practice more appropriate to the time constraints of clinical practice.

Several other clinical implications of this finding need to be considered for the thesis as a whole. Firstly, the importance of a P-BOM and the Performance Profile is to gather important information from the patient's perspective. This information contained within each P-BOM needs to be useable by a clinician to determine the relevant course of action, when using such information to justify clinical decision-making (Michener, 2011; Lavoie et al., 2001).

Within the profiling literature, athletes' profiles are generally reduced to the ten or twenty most important items as determined by their importance ratings. However, patients within rehabilitation programme of care may differ to athletes, as it could be argued that athletes profile items would be stable, in contrast to a clinical setting whereby items (constructs) are heterogeneous (Batterham and George, 2003). Further, the profiling items identified at pre-surgery by patients could potentially be very different to the items that could elicited at the later stages of rehabilitation. Therefore, it would be appropriate not to reduce patient's profiles to a 5 item version, and similarly a 10 item version, but allow patients to have a wide array of self-perceived needs, with an option to add other profile items, to assist in patient-physiotherapist negotiation to optimise attainment of the desired improvements.

As discussed, an understanding of the reliability characterises of the importance ratings, lowest to highest as selected by patients, would be important here and warrants further investigation. Despite this lack of understanding, it can be assumed that a 10-item inventory would be more useful for data analysis. Moreover, 10 item profile would allow practitioners to understand patient's self-perceived physical needs whilst allowing for a range of other items within patients' Performance Profile which may be selected at a different point in their rehabilitation, since another item (for example pain) would be less expected at the intermediate or late phases of ACL rehabilitation as opposed to immediately post-ACLR surgery. Future research would be required to investigate the items (constructs) identified within patients Performance Profiles at various time-points across patients' rehabilitation process, to understand how profile items over time might change. Further will facilitate an understanding of the number of profile items to described patients self-perceived needs following ACL injury. In the latter, if a fixed profile was adopted, future research would be required to evaluated what items/items (constructs) would be suitable for a generic fixed profile and the reliability characteristics re-evaluated similar to the protocols of this study.

6.6.4 - To ascertain the time taken to enter items in the Performance Profile and complete the importance ratings for each item, with a view to establishing the efficacy of the technique compared to more traditional methods used in clinical practice

The Performance Profile requires time to be delivered correctly (introduction and elicitation of Performance Profile ranging between 6.32 to 12.52 minutes), and the study results indicate that the Performance Profile is comparable or quicker to some of the more traditional P-BOMs such as the IKDC, which is reported to take a total of 10 minutes to administer and 5 minutes to score (Collins et al., 2011) **(TABLE 58)**. However, an additional advantage of the Performance Profile over other P-BOMs is that the Performance Profile can be used as both an assessment tool and management outcome measure concomitantly, within a relatively easy manner. As the Performance Profile construction and ease of interpretation differs from traditional P-BOMs, such as the IKDC and KOOS.

Indeed, the Performance Profile can be interpreted without scoring thanks to the visual representation of patients' needs, therefore its simplistic nature may be more suited to the time constraints of clinical practice and consequently more feasible and less burdensome administratively (or clinician friendly) for physiotherapists. Moreover, no previous study has investigated use of the Performance Profile on any symptomatic population within orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways (Doyle et al., 1998; Gleeson et al., 2008).

TABLE 58 - Edited and adapted from Collins et al., 2011. Reported values for number of items per P-BOM, the time to administer (respondent burden), and time to score each patient-based outcome measure by hand (administrative burden).

	IKDC	**LYSHOLM**	**KOOS**	**CINCINNATI**
Number of items	18	8	43	22
Time to administer (mins)	10	-	10	-
Time to score (mins)	5	5	5	-

As identified in the present study, the time taken to complete subsequent Performance Profiles was 1:18 to 3:38 minutes confirming that the Performance Profile maybe a quicker method of assessment than traditional P-BOMs following the initial introduction and elicitation of each patient's Performance Profile. It can clearly be seen that the IKDC and KOOS (P-BOMs) take up to 10 minutes to complete and another 5 minutes to be evaluated by the clinician. So despite, the fact that the Performance Profile initially takes 6.32 to 12.52 minutes to explain and complete by the patients, re-evaluation of the Performance Profile (i.e., 1:18 to 3:38 minutes) compared to the IKDC and KOOS would be comparably faster. Future research would be required to evaluate this more precisely with other P-BOMs, to confirm the efficacy of the Performance Profile.

As current practice also deploys electronic versions of P-BOMs to document outcome (see Bojcic, Sue, Huon; Maletis, and Inacio, 2014) in the interests of reducing time spent by patients using pen and paper methods to increase the efficiency of P-BOM completions, reducing errors, increasing accuracy and for ease in the interpretation of patients results. It would be further of interest to examine an electronic version of the Performance Profile within clinical practice alongside other electronic version of P-BOMs, and versus tradition pen and paper P-BOMs to establish whether these electronic versions do provide greater discrimination of reliability than traditional pen and paper methods (Duracinsky et al., 2014).

Three of the six completions of patients' Performance Profiles were completed at home and no significant systematic learning trends were observed across these assessment occasions, evaluated by one-way repeated measures ANOVA ($F_{(40,4)} = 1.9$, *ns*). This would further suggest that patients were able to complete Performance Profile at home with no concerns and without requiring supervision. One aspect of feasibility of a new outcome measure would be to ensure patients do not require supervision when completing the Performance Profile, which this study partially supports.

Future research would be required to examine the practical utility of the Performance Profile in relation to its appropriateness, acceptability, as well as to other aspects of feasibility, as discussed by Vailer et al. (2015). Along this line of thought, it would be equally advantageous to investigate psychometric measurement properties, to further include the evaluation of reliability and ability of the Performance Profile to detect change, whilst understanding other aspects of validity and interpretability (i.e., minimum important difference), to other symptomatic populations, to further substantiate its practical application within clinical practice.

6.7 - Conclusion

In preparation for the second clinical deployment of the Performance Profile, a prospective random-allocation-to-group trial involving a patient-physiotherapist negotiation using the Performance Profile, will be modified periodically through a rehabilitation programme of care, to optimise attainment of the desired improvements **(Study 4: Intervention RCT investigation)**. Therefore, it was important to investigate and substantiate aspects of Performance Profiling in terms of its day-to-day reliability characteristics, responsiveness to change, and to evaluate its clinical utility in this clinical setting. The importance of describing and understanding the reliability characteristics was to ensure patients could accurately rate their own self-perceived needs consistently overtime, in a relatively controlled setting. This would facilitate the Performance Profile's proper use as an assessment tool in this thesis and potentially, within wider clinical practice.

In light of the above, and with the recent transference of the Performance Profile to a clinical setting (Gleeson et al., 2008; Yates et al., 2016), no study has yet investigated its use as a management tool in this context, and only one randomised trial has investigated this use in athletes alone (Weston et al., 2011b), despite tremendous support for its use in both athletic research and within the athletic population itself (Butler, 1997; Jones, 2003; Doyle and Parfitt, 1997; Gleeson et al., 2005; Weston et al., 2013). Moreover, no previous study has investigated use of the Performance Profile on any symptomatic population within orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways (Doyle et al., 1998; Gleeson et al., 2008).

Previous literature has focused solely on use of the Performance Profile among athletes, yet it has been suggested that it lacks sufficient measurement sensitivity to accurately rate the relatively small changes in performance and self-perceived capability observed in this population (Doyle et al., 1998; Gleeson et al., 2005). Therefore, with respect to the Performance Profile's transference to a clinical population, as suggested in this study, its clinical utility and responsiveness to change during a dramatic period following ACLR surgery have been demonstrated. While this study has only examined this pre- and post-ACLR, descriptively, it would seem more beneficial to examine the technique's responsiveness more empirically, to detect meaningful or important changes of the Performance Profile in a clinical state (Roach, 2006; Valier and Kenneth, 2015).

A subsidiary aim of this study was to assess whether the first five reported self-perceived physical needs identified and rated as most important, provide a more accurate discrimination of reliability compared to the first 10 or 15 items self-perceived physical needs rated most important from each patient's Performance Profile evaluated over five repeated administrations. It was found that the first five provided a slightly more accurate discrimination of reliability, compared with the first ten or fifteen. Therefore, as in the Performance Profiling literature in which each Performance Profile is reduced to the ten most important qualities perceived to be important for data analysis with little or no justification, it was considered safe to assume in this thesis that patients' Performance Profiles could be reduced to the ten most important items (constructs) for the purposes of data analysis.

In a practical sense, using either 5 or 10 of the items could make deployment of the Performance Profile in clinical practice more appropriate given the time constraints often imposed. As identified in the present study, the profile approach requires time to be delivered correctly (introduction and elicitation of Performance Profile ranging between 6.32 to 12.52 minutes). However, the time taken to complete subsequent profiles was completed within 1:18 to 3:38 minutes confirming that the Performance Profile maybe a quicker method of assessment than traditional P-BOMs following the initial introduction and elicitation of each patient's Performance Profile. It can clearly be seen that the IKDC and KOOS (P-BOMs) take up to 10 minutes to complete and another 5 minutes to be evaluated by the clinician. So despite, the fact that the Performance Profile initially takes 6.32 to 12.52 minutes to explain and complete by the patients, re-evaluation of the Performance Profile (i.e., 1:18 to 3:38 minutes) compared to the IKDC and KOOS would be comparably faster.

An additional advantage of the Performance Profile over other P-BOMs is that the Performance Profile can be used as both an assessment and management outcome measure concomitantly, within a relatively easy methodology, which appears to be patient- and clinician-friendly. It may also be more practical to have a fixed profile as in previous profiling literature, providing patients with a ready-prepared profile containing predetermined items. Use of such a profile requires investigation, however, to substantiate its use, although it could be argued that having a fixed profile could allow the first stage of Butler and Hardy's (1992) procedure to be omitted giving it a faster completion time than more conventional P-BOMs used in clinical practice.

Lastly, the Performance Profile has demonstrated sufficient psychometric characteristics to substantiate its preliminary use within the thesis and can be applied immediately in a clinical setting (and other symptomatic populations), without extra cost.

CHAPTER SEVEN

STUDY 4

Effects of Reconstruction Surgery and Individualised Rehabilitation on Neuromuscular, Sensorimotor and Musculoskeletal Performance in Patients with Anterior Cruciate Ligament (ACL) Deficiency

7.1 - Introduction

Contemporary rehabilitation practice is suggested to be influenced by two paradigms, known as Evidence-Based Medicine and Patient-Centred Medicine (Bensing, 2000). Evidence-Based Medicine is firstly defined as the integration of clinicians' individual expertise with the use of validated scientific evidence in making appropriate decisions about the care of individual patients (Sackett et al., 1996). The main objective of Patient-Centred Medicine on the other hand, is to improve health outcomes of individual patients throughout clinical practice, while taking into account the patient's goals, preferences and values (Meyer, 2012), as well as the available economic resources. Patient-Centred Medicine is a newly evolving field working alongside the concepts of personalised medicine and tailored therapeutics (Sacristán, 2013). In recent years, it has become clear that 'bridging the gap' between the paradigms of Evidence-Based Medicine and Patient-Centred Medicine is essential in optimising good clinical outcomes (Bensing, 2000).

Further, Patient-Centred Medicine implies a paradigm shift in the relationship between physiotherapists and their patients. Fundamentally, changes are not required in the individuations of treatment strategies, but more within the individualisation process of therapeutic decisions, where the patient's goals, preferences, values as well as the available economic resources play an essential role (Lee, Choo, Cho, and Lee, 2012). The literature regarding patient preference for different treatment options, where alternatives exist, is sparse and the concept requires further investigation (Bowling and Ebrahim, 2001; Brindis and Sennett, 2003).

The concept of a shared decision-making process between the patient and the physiotherapist has been an integral component of patient-centred approaches (de Haes, 2006), and has been an aligned approach in strengthening such patient-centred care in medical rehabilitation (Faller, 2003). Essentially, communication is considered a central component of patient-centred care (Bensing et al., 2000; Cooper et al., 2009) and, more recently, the concepts of both patient-centeredness and the shared decision-making process have been advocated as the starting points for effective communication for the delivery of patient-centred approaches (Ishikawa et al., 2013). Furthermore, to 'bridge the gap' between both paradigms of Evidence-Based Medicine and Patient-Centred Medicine (as previously discussed), Evidence-Based Medicine should include research based on an understanding of patient preferences in randomised controlled trials, and equally, Patient-Centred Medicine should become more evidence-based by focusing more research investigating effective communication strategies in their study designs (Torgerson and Sibbald, 1998).

It can be argued, however, that the inclusion of patient needs and preferences within the decision-making process may not always be suitable or clinically inappropriate (see de Haes, 2006). Therefore, the inability of a patient to fully participate in and contribute to their own rehabilitation programme of care, where their needs and preferences are not considered due to them being clinically inappropriate, can subsequently influence the level of patient-centeredness within the patient-physiotherapist relationship (Leach et al., 2010). It therefore seems unclear at present precisely how patient-centred care should be adopted into physiotherapy practice and how physiotherapists can effectively integrate this approach into their own daily practices (Cooper et al., 2009; Ishikawa et al., 2013).

Within the rehabilitation process itself, physiotherapists are required to continually assess/monitor and justify clinical decision-making (Michener, 2011) and these measurement tools are labelled as 'outcome measures' (Irrgang and Lubowitz, 2008). Historically, the use of outcome measures was not an integral part of routine clinical practice for physiotherapists (Tuttle, 2009). In the past, physiotherapists assessed the effectiveness of their clinical practice from observations either through an objective examination using clinician-derived outcomes and/or from the patient's perspective (subjectively asking), measured by patient satisfaction (or dissatisfaction) with the physiotherapy treatments (Mehta and Grafton, 2014).

However, in the past two decades, increasing emphasis has been placed on Evidence-Based Medicine in physiotherapy to incorporate P-BOMs[128] and C-BOMs[129] as a means to comprehensively evaluate overall knee function from the perspective of the patient and the physiotherapist, and to assess, evaluate and justify clinical decision-making during the ACL rehabilitation process (Bradbury et al., 2013). More specifically, C-BOMs are primarily used to evaluate impairment (an objective measurement consisting of a physical assessment such as hop-based outcome for distance or time), while P-BOMs (i.e., IKDC) are for the self-evaluation of Activity Limitations (activities) and Participation Restriction (participation from the perspective of a patient) (Michener, 2011). Further, P-BOMs are necessary to understand what is important to a patient, to evaluate care, and in some instances, to assist in clinical decision-making processes (whilst documenting outcome), from the perspective of clinicians, to guide the treatment options available to their patients within clinical practice (Michener, 2011; Irrgang and Lubowitz, 2008; Bradbury et al., 2013; Valier and Kenneth, 2015).

The current literature seems to suggest that physiotherapists do not routinely use P-BOMs in their current physiotherapy practice (Copeland et al., 2008; Jette et al., 2009; Swinkels et al., 2011). Dierck et al., (2013) illustrates that physiotherapists often do not incorporate patient preferences or values within their decision-making process, or even allow patients to provide their opinions about the proposed treatment plan. Although there are varying degrees of subjectivity involved in most physiotherapists' assessments, such as functional status and quality of life (QoL), and patient satisfaction, which can be more precisely reported by the patients themselves rather than by the clinician (Lloyd et al., 2014). C-BOMs (providing an objective measurement of impairment),

[128] Patient-Based Outcome Measure (P-BOM).
[129] Clinician-Based Outcome Measure (C-BOM).

however, are not subject to a large degree of individual interpretation, and are more likely to be reliably measured across patient recovery (or across a study design) by different healthcare professionals and over time (Velentgas et al., 2013), which perhaps explains this greater reliance on C-BOMs to justify clinical decisions regarding the management and treatment planning of patients, with less inclusion of P-BOMs. Several key discussions within the thesis have addressed the potential reasons why clinicians may not be using P-BOMs within their own clinical practice (see p. 114)

An outcome measure known as Butler and Hardy's (1992) Performance Profile has been reported to offer practitioners a precise estimate of an athlete's and injured patient's self-perceived needs in preparation for sport or following injury, respectively (Weston et al., 2011b; Gleeson et al., 2005; Gleeson et al., 2008; Yates et al., 2016). Fundamentally, the Performance Profile is described as a patient-specific or individualised outcome measure. This type of outcome measure has been recently recognised as another means of patient assessment within clinical practice (Dekker et al., 2005; Donnelly and Carswell, 2002). Individualised outcome measures refer to those assessments and outcome measures in which the problem areas perceived are measured specifically for each individual patient's needs and this can be established by either the patient or the clinician at the time of construction (Khorsan et al., 2008). For example, the patient constructing an individualised outcome measure is allowed to select his or her own issues, domains or concerns as to what outcomes have personally been affected since the time of injury (Fitzpatrick et al., 1998), and consequently, this method of assessment has not been defined based on predetermined questions and a standardised list of potential answers (Fitzpatrick et al., 1998; Ruta and Garratt, 1994).

Within the Performance Profiling procedures, allowing patients to discuss their own self-perceived needs, the construction of individual profiles and their interaction with physiotherapist would potentially increase autonomy and heighten perception of relatedness (Deci and Ryan, 1985). The adeptness of the Performance Profile to enable patients to monitor their own progress could improve perceived competence as athletes/patients see their profile ratings increase over time, further supporting the ability of Performance Profiling to optimise athlete's motivation in their own training (Weston et al., 2012). Deci and Ryan's (1985) Cognitive Evaluation Theory (CET) is important here, since its focus is on patient motivation which few studies have yet examined along with motivational factors in the context in which the injury has taken place (King-Chung Chan, Hagger, and Spray, 2010).

Butler and Hardy (1992) originally proposed using the Performance Profile to assess athletes' perceived needs followed by a tailored guided intervention management programme. However, only one study, conducted in 2011, has used this investigation design to examine the impact of a repeated Performance Profiling intervention on athletes' intrinsic motivation (Weston et al., 2011b). That study's findings were encouraging, suggesting that single use of the Performance Profile led to no significant improvement in athletes' intrinsic motivation, while three repeated completions during a competitive six-week season improved motivation significantly. Quite interestingly in this study, athletes were instructed to select up to three items from those identified within their individual profile which required the greatest improvement. These items were then discussed with the athletes' coaches to determine how best to achieve these necessary improvements. Indeed, within a clinical commentary, Doyle and Parfitt (1998) discuss the rationale for incorporating the Performance Profile within a clinical setting, how this profiling technique could be adopted as a means to assess patients' perceived needs, and how these perceived areas for improvement could be used to manage patient care throughout a structured patient-centred rehabilitation programme (Doyle and Parfitt, 1997; Gleeson et al., 2005; Gleeson et al., 2008) **(FIGURE 5**; p. 60**)**.

In light of the above, and with the recent transference of the Performance Profile to a clinical setting (Gleeson et al., 2008; Yates et al., 2016), no study has yet investigated its use as a management tool in this context[130], and only one randomised trial has investigated this use in athletes alone (Weston et al., 2011b), despite tremendous support for its use in both athletic research and within the athletic population itself (Butler, 1997; Jones, 2003; Doyle and Parfitt, 1997; Gleeson et al., 2005; Weston et al., 2013). Moreover, no previous study has investigated use of the Performance Profile on any symptomatic population within orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways (Doyle et al., 1998; Gleeson et al., 2008).

7.2 - Aims and objectives

The principal aim of this study **(Study 4)** is to investigate the effects of encouraging each patient to self-perceive and manage areas of physical self-perceived needs within standardised and periodic routine negotiations during scheduled physiotherapy appointments with the physiotherapist during rehabilitation following ACLR surgery, using a valid patient-centred, idiographic technique and a strategy termed the Performance Profile, developed by Butler and Hardy (1992). This negotiation process will potentially be a means of developing a more structured and enhanced patient-centred programme of care.

[130] In accordance with a P-BOM definition, which is defined as any outcome measure that is directly assessed from the patient's perspective on any health status without the interpretation of the patient's response by a clinician (Deshpande et al., 2011), this measure of subjective/self-report from a patient's perspective (which is not directly interpreted by a clinician) will be referred to as an 'assessment outcome measure' only. However, when an outcome measure (for example the Performance Profile) is interpreted, and then used as a means to manage subsequent rehabilitation, this process will be referred to as a management tool or management outcome measure.

All participants will elicit an individualised Performance Profile within a two-week period prior to their ACLR surgery[131]. The systematic deployment of the Performance Profile, prior to physiotherapy appointments, will provide a means for the physiotherapist (within an assessment phase) to perform a quantifiable evaluation of the self-perceived deficiencies identified by each patient. Subsequently, through the routine evaluation of patients own Performance Profile (and a guided intervention management programme based on those needs), the care delivery pattern and content of the conditioning will be modified periodically through a Performance Profile Management (PPM) group involving rehabilitation conditioning modified periodically through patient-physiotherapist negotiation to optimise attainment of the desired improvements.

The rehabilitation control (CON) group will comprise of a standardised and well-established (>12 years) programme of exercise rehabilitation used in current clinical practice (24 weeks of structured and supervised rehabilitation conditioning [estimated: 705 ± 10 minutes])[132] focusing on progressive mobility, strength and endurance conditioning (see p. 439). The experimental design of Study 4 will ensure that the overall duration, volume, modes and intensity of exercise rehabilitation conditioning associated with the PPM rehabilitation group will be precisely matched to that of the contemporary (control [CON]) rehabilitation group, but the PPM rehabilitation group will include the novel undertaking of an individualised rehabilitation programme (PPM).

Within the PPM rehabilitation group, each participant will be required to determine the relative importance of each self-perceived need, as in previous research (Weston et al., 2011). They will be asked to rank their Performance Profile items in order of importance and those requiring greatest improvement (and priority of treatment) to obtain full recovery. The five areas identified from the ratings as most important from the patient's perspective will be used to initiate discussions between the patient and physiotherapist on how best to achieve the desired improvements from the patient's perspective. They will then negotiate and agree upon the content of any subsequent rehabilitation and treatment strategies (where clinically relevant) according to the factors determined previously that are essential to obtain full recovery.

The IKDC is the primary outcome measure used to evaluate patient outcome and primary end point. The methodologies for evaluating treatment effects on P-BOMs (primary end point) do not differ principally from the methodologies used for evaluation of other treatment effects (Altman 1991). There are, however, some aspects that are important when using P-BOMs as a primary end point in clinical studies. One important consideration is that the instrument used for measuring the

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[131] Anterior Cruciate Ligament (ACL) Reconstruction (ACLR).

[132] The programme of rehabilitation comprised a standardised and established (>12 year) structured and supervised rehabilitation conditioning programme which estimated time spent in rehabilitation to be approximately: 705 ± 10 minutes, focusing on progressive mobility, strength and endurance conditioning (see RJAH, 2007).

outcome should be validated. The IKDC is widely accepted and used within the international research community and has been shown to be valid. In particular, content validity (i.e., patient input into the relevant concepts for measurement), construct validity, reliability, responsiveness (i.e., effect size and the proportion of people who respond to the treatment by reaching a Minimal Clinically Important Difference (MCID), and interpretability have been assessed in previously studies on the target population[133]. In line with the above, this thesis has provided detailed sections on the IKDC (as well as other P-BOMs) in the methods section (see p. 168), and the importance of MCID and determining Minimally Detectable Change (MDC) are presented later on, confirming that the IKDC can be deployed in the thesis as a primary outcome measure and is an acceptable outcome for evaluating primary end point (Gleeson et al., 2002; Minshull et al., 2007; Bailey et al., 2015).

In accordance with the International Classification of Functioning, Disability and Health (ICF) model, study outcomes will also be evaluated by a combination of P-BOMs[134] (VAS [Pain], KOOS, Lysholm, and Performance Profile) and C-BOMs[135] (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) to assess overall knee function following ACLR surgery **(**see **FIGURE 2**; p. 44**)** within contemporary practice. It is worth noting that the majority of P-BOMs and C-BOMs within this thesis (i.e., Single-Leg Hop for distance, IKDC, KOOS, and Lysholm) are currently deployed at the rehabilitation and physiotherapy centre (Robert Jones and Agnes Hunt Orthopaedic Hospital (RJAH), Oswestry, UK).

In addition, the novelty of this study was the inclusion of the contralateral limb (non-injured limb) as a means to evaluate change compared to the injured leg. Although some physiological deconditioning of this control leg's capabilities was likely to have occurred due to altered physiological loading in the period between ACL injury and ACLR surgery, it nevertheless represented a best estimate of a reference (baseline) for performance capability (Gleeson et al., 2008; Bailey et al., 2014). Evidence from Study 3 **(Study 3: Reliability investigation)** has shown that the Performance Profile of the non-injured limb remained constant at pre-surgery and following ACLR surgery, with a non-significant difference between the injured and non-injured limbs pre- and post-ACLR surgery, suggesting that the non-injured leg scores by the Performance Profile were not affected by ACLR surgery. Thus, it can be argued that when attempting to identify levels of 'normal' or improved function brought about by ACLR surgery and subsequent rehabilitation, the use of the contralateral asymptomatic leg as a baseline and control is indeed necessary (Clark 2001,

[133] Consult p. 166 for discussions on MCD/MCID, and associated values reported from literature.

[134] Patient-Based Outcome Measures (P-BOMs).
[135] Clinician-Based Outcome Measures (C-BOMs).

Hopper et al. 2002, Reid et al. 2007, Thomee et al. 2011). As such, other C-BOMs and comparisons to the non-injured leg should also be evaluated to assist in the assessment of the study outcomes.

7.2.1 - Research hypothesis

- Null (*Ho*): The effect of Performance Profile Management (PPM) on the P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, SMP-FE, PF, EMD, and RFD), over a period of standardised clinical care, would be equivalent to that of contemporary (CON) clinical practice, in a clinical population undergoing knee ACLR rehabilitation.

- Alternative: The experimental hypothesis is that the effect of Performance Profile Management (PPM) on the P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, SMP-FE, PF, EMD, and RFD), over a period of standardised clinical care, would offer superior outcomes to those delivered by contemporary (CON) clinical practice[136], in a clinical population undergoing knee ACLR rehabilitation.

Two secondary aims within this study will be investigated. Firstly, musculoskeletal injury rehabilitation outcomes are reportedly determined by a variety of anthropometric characteristics, orthopaedic-associated factors (Holla et al., 2013; Vincent et al., 2006, Lohmander et al., 2004) as well as environment and dose of exercise (Riseberg, 2004, Renstrom et al., 2008; Hewett et al., 2006). Indeed, a prospective clinical trial examining the clinical efficacy and effectiveness of a total hip replacement revealed that being a younger patient and self-reporting high levels of pre-surgery function were good predictors of a post-rehabilitation positive clinical outcome (Smith et al., 2012). It has, moreover, been demonstrated that potential characteristics related to old age like a higher BMI are associated with increased clinical problems and an equivalent increase in treatment cost for patients with knee joint injuries (Vincent et al., 2006, Lohmander et al., 2004). These effects are likely the result of degenerative changes in the joint (Holla et al., 2013). Evidence gathered relating to back disorders and specifically injuries to the spinal cord demonstrates that a long surgery waiting time is linked to negative rehabilitation outcomes (Braybrooke et al., 2007, Derrett et al., 1999). This could be explained by the physiological de-conditioning that a longer surgery waiting time would likely induce if no pre-surgery maintenance conditioning was undertaken. While there is currently no literary or clinical evidence of the effects of a long surgery waiting time on recovery

[136] Although it is difficult to establish from previous research an agreed Minimal Clinically Important Difference (MCID) (see p. 166) for P-BOMs and C-BOMs, it can be suggested that an up to 15% improvement following the PPM interventions post-ACLR surgery might represent sufficient clinical efficacy to validate its application in clinical practice (Davidson and Keating, 2014).

from knee joint injuries from either RCTs, systematic or meta-analytic reviews, it would be reasonable to state that such influential factors might also apply to rehabilitation issues relating to serious knee injuries.

Therefore, an investigation into the influence of anthropometric and orthopaedic-related factors (height [cm], body-mass [kg], time from injury to surgery [days], number of physiotherapy sessions, and unstructured physical activity [strength, flexibility, and cardiovascular conditioning (time)] would be necessary to statistically assess whether they affected the relationships amongst P-BOMs and C-BOMs at pre-surgery and across all rehabilitation phases. Factors like waiting time for surgery, which could not be experimentally-controlled within this study's design, and other influences like patients' anthropometric characteristics and orthopaedically-relevant factors have been shown to correlate to these clinical outcomes (Holla et al., 2013, Vincent et al., 2006, Lohmander et al., 2004) and are important aspects to consider.

Secondly, the last subsidiary aims will be to investigate the measurement issue associated with comparing pre- and post-intervention scores for P-BOMs and C-BOMs with a view to discussing whether the change scores may be due to random measurement error, real change in health status, or both (Busija, Osborne, Nilsdotter, Buchbinder, and Roos, 2008). The outcome of this study will descriptively assess the percentage (%) change scores from pre-ACLR surgery (baseline) scores versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for both P-BOMs and C-BOMs. The defined assessment occasions of 6, 12, and 24 weeks post-ACLR surgery will correspond to the acute, intermediate, and late phases of rehabilitation. Within change scores, C-BOMs evaluated injured and non-injured limbs associated with the knee flexors and knee extensor musculature separately.

Responsiveness is defined as the ability of an outcome measures to detect meaningful or important changes in a clinical state, and has been advocated as an essential property of outcome measurement to measure change and the effectiveness of interventions (Roach, 2006; Valier and Kenneth, 2015). A subsidiary aim of Study 3 **(Chapter 6: Reliability investigation)** was to examine the responsiveness of the Performance Profile completions pre-surgery (one day before) versus post-ACLR surgery (one day after). In brief, following ACLR, patients perceived a 3.34-unit reduction in the performance of the injured limb (57.7% decrease in Performance Profile knee performance) compared to a 0.13-unit reduction in performance of the non-injured limb, illustrating the Performance Profile's sensitivity and responsiveness in detecting post-ACLR changes in performance. The descriptive analysis of the reduction in self-perceived capability for the injured limb compared to the non-injured limb provides the first evidence to support the responsiveness of the Performance Profile to detect changes following ACLR surgery. The ability of a P-BOM/C-BOM to detect a meaningful change is also known as sensitivity; outcome measures that are more sensitive would in turn be able to detect smaller changes in capability. However, relatively few studies have specifically examined the magnitude and meaningfulness of changes within a range of outcome measure scores following orthopaedic surgery, and mixed results have been reported in those that have (Briggs et al., 2009; Nilsdotter, Roos, Westerlund, Roos, and Lohmander, 2001; Escobar, Quintana, Bilbao, Arostegui, Lafuente, and Vidaurreta, 2006).

Study 4 aims/objectives are summarised in **TABLE 59** (next page).

TABLE 59 - Study 4 aims and objectives.

STUDY 4	**To investigate the effectiveness of self-management and negotiation of self-perceived physical needs between patient and physiotherapist in a novel patient-centred approach compared to contemporary practice.**
Chapter 7 Intervention RCT investigation	**(1)** To investigate the effects of self-management and negotiation of self-perceived physicals needs utilising the novel deployment of the Performance Profile (Performance Profile Management [PPM]: patient-centred, idiographic profiling assessment/management tool) between patient and physiotherapist compared to a contemporary [CON] rehabilitation group. The evaluation of overall knee function following ACLR surgery was conducted using the World Health Organisation's (WHO) International Classification of Functioning, Disability and Health (ICF) disablement model as evaluated by P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg-Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE). **(2)** To evaluate the influence of P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile), C-BOMs (Single-Leg Hop for distance, ATFD, PF, EMD, RFD, and SMP-FE), together with anthropometric and orthopaedic-related factors (height [cm], body mass [kg], time from injury to surgery [days], METs, and unstructured physical activity [strength, flexibility, and cardiovascular conditioning (time)]), between PPM and CON rehabilitation groups at pre-surgery. **(3)** To investigate the responsiveness of P-BOM and C-BOM via their percentage (%) change scores from pre-ACLR surgery (baseline) scores versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups[137].

[137] The defined assessment occasions of 6, 12, and 24 weeks post-ACLR surgery will correspond to the acute, intermediate, and late phases of rehabilitation. Within change scores, C-BOMs evaluated injured and non-injured limbs associated with the knee flexors and knee extensor musculature separately.

7.3 - Methods

In parts, this methodology section has been truncated, in brief, the assessment procedure and protocols deployed throughout this study have been provided - where indicated please consult general methods section **(Chapter 4**; p. 162**)**, where appropriate for full descriptions of specific methodologies are found. All data collection was undertaken within a two-week period prior to each patient's ACLR surgery, and post-ACLR surgery and within 24 weeks of physical rehabilitation. Patients were assessed on four separate occasions (pre-surgery, and at 6, 12, and 24 weeks post-ACLR surgery. Post-ACLR surgery, all patients were treated and assessed by the same physiotherapist for the duration of their rehabilitation period. Patients who met the inclusion and exclusion criteria were recruited over an 18-month period from December 2010 to August 2012.

7.3.1 - Participants

Forty-six patients (41 males [age at surgery (years): 31.6 ± 12.7 (range 16 to 63); height (cm): 176.3 ± 5.1; body-mass (kg): 80.5 ± 9.1]; 5 females [age at surgery (years): 28.0 ± 11.7 (range 16 to 43); height (cm): 162.1 ± 4.3; body-mass (kg):64.2 ± 8.9]), electing to undergo unilateral ACLR surgery (central third, bone-patella tendon-bone graft [n=3], or semitendinosus and gracilis graft [n=43]) at Robert Jones and Agnes Hunt Orthopaedic and District Hospital (NHS Foundation Trust hospital), Oswestry (UK), gave their informed consent to participate in the study.

Participants were initially recruited from a cohort of patients presenting with arthroscopically verified unilateral complete ACL rupture at the hospital over a 12-month period. Patients meeting inclusion and exclusion criteria (see p. 163) were eligible for this study and were offered participation. In brief, no exclusions were made on the basis of gender or race, and patients over 16 years old who were deemed musculoskeletally and mentally mature were invited to participate. Patients suffering with bilateral knee pathologies at the time of consent were excluded as the contralateral knee would not suffice in acting as a control limb. Furthermore, patients with systemic conditions such as rheumatoid arthritis, chronic obstructive airways disease, or cardiac pathology were excluded on the basis that their physiological responses to training would be compromised and their physical ability to take part in the rehabilitation programme would prove difficult and clinically inappropriate.

The study was discussed with all eligible patients, including the potential risks and benefits and a Patient Information Sheet **(**see **APPENDIX 10**; p. 573**)** and Participation Consent Form **(**see **APPENDIX 11**; p. 578**)** were issued. All participants were fully aware that they could withdraw from the study without giving any reason and this would in no way alter the care they received. Patients were treated by four consultant orthopaedic surgeons of similar experience and practice (> 16 years) using agreed and matched surgical procedures (> 14 ACLR surgeries performed per month). All participants received ACLR surgery on average 201.9 ± 109.8 days (range: 18 - 477 days) following injury to ACLR surgery. All participants were not given feedback of results until after the completion of the study.

TABLE 60 summarises patient allocation to each rehabilitation groups, anthropometric and clinically-related characteristics of each patient.

	Rehabilitation Group	
	PPM	**CON**
Male (n):	20	21
Female (n):	3	2
Age at surgery (years):	35.0 ± 14.2	27.5 ± 9.5
Height(m):	173.7 ± 7.6	175.6 ± 5.5
Body-mass (kg):	76.7 ± 8.9	80.7 ± 11.3
Time from injury to surgery (days):	164.9 ± 87.4	153.3 ± 118.9

7.3.2 - Sources of bias and Intention to Treat analysis

The quality of clinical trials may be defined as the confidence that the design, conduct, report, and analysis restrict bias in the intervention comparison (see Pannucci and Wilkins, 2010). In order to minimise the possibility of bias in the results, Study 4 was designed as a large-scale exploratory/feasibility trial with a prospective and experimentally-controlled, longitudinal design with repeated measures, which used a contralateral limb as an additional control, with a random selection of subjects, in which patients undergoing post-ACLR surgery and rehabilitation were subjected to different care pathways. During the experimental period, minimising bias and controlling for external validity of the studies' findings were considered, for example, blinding of the physiotherapist and assessor was not feasible due to the educational nature of this research and the associated budget limitations. Similarly, individuals involved in data analysis were not blinded to some aspects of the data (assessment occasions and group allocations) and this may have contributed to bias in the results (see discussion section of this study for an evaluation of the limitations and potential bias of Study 4).

Due to the merits of same environment and randomisation in this clinical trial, some aspects of potential bias may have been controlled. However, other uncontrolled determinants for rehabilitation in this study, including not controlling for anthropometric characteristics and orthopaedically-relevant factors might still have the potential to affect the final outcome of the findings of Study 4. Considerable attempts were made to ensure iso-volumetric rehabilitation dosage amongst the two main arms (PPM; CON) were evaluated. Therefore, inter-patient and inter-group differences in the rehabilitation dosage might affect the responses within the trial and hinder the correct attribution of effect by the PPM intervention. To add further complications, participants were not confined to attend a mandatory number of physiotherapy appointments post-ACLR surgery. Instead, they would attend routinely allocated physiotherapy appointments under the clinical guidance of the physiotherapist and relevant hospital policies. As these aspects could not be controlled logistically within the experimental design, they were controlled statistically, as necessary.

As with all research, controlling and understanding bias, including an Intention to Treat (ITT) analysis, has become a 'gold standard' strategy allowing a methodological reviewing process to evaluate the quality of clinical study outcomes by analysing which patients were randomised to either a control or to experimental group conditions at a beginning of a clinical study, irrespective of non-compliance, administrative errors, withdrawal from study, or other protocol deviations, and anything that happens after the randomisation allocation procedures (Gupta, 2011). Disclosing any deviations from the random-allocation procedure, reporting missing responses to assessment occasions post-randomisation are principle components of the Intention to Treat approach/strategy (Hollis and Campbell, 1999).

Using the ITT analysis in this manner is reported to improve clarity, consistency and overall transparency of reporting clinical outcomes. The method is advocated by many policy makers and evidence-based research groups (i.e., CONSORT [Consolidated Standards of Reporting Trials] statement and Cochrane Collaboration groups etc.) as a means of ensuring an accurate comparison of PPM and CON rehabilitation groups, with less potential bias (Olivo et al., 2008). More specifically, the CONSORT group suggests that to improve the quality of clinical studies, the number of patients in each control group condition should be analysed using the "Intention to Treat" principle (Begg et al., 1996; Heritier, Gebski, and Keech, 2003). Procedures for patient recruitment, randomisation and allocation to rehabilitation groups, including the number of excluded patients and the reasons, lost to follow-up cases, and Intention to Treat through study assessment occasions are all summarised in the CONSORT flow chart **(FIGURE 48**; p. 354**)**.

Although Study 4 will have inherited uncontrollable aspects of bias (as discussed above) that cannot be controlled, an examination of other aspects of the CONSORT checklist would allow consideration of aspects of bias, other than the Intention to Treat analysis that has been discussed here. The outcome of potential sources of bias, including the Intention to Treat findings are discussed elsewhere in this thesis (p. 352).

7.3.3 - Intervention

All patients treated by the same physiotherapist and followed a standardised and established program of rehabilitation used in current clinical practice (RJAH, 2007) **(**see **APPENDIX 1**; p. 440**)**. In summary, all the rehabilitation groups (PPM; CON) followed the same rehabilitative guide with respect to the progression of activity and function. This is largely dictated by the healing process of the graft tissue. On average, it takes approximately 6 weeks to overcome the insult of the surgery with respect to activity and function. During this acute phase, rehabilitative exercises are progressed as the patients' symptoms allow. For up to 3 months following surgery, physical restrictions are placed on performing open kinetic chain quadriceps exercises, running and twisting and turning on the knee. However, from this point, the restrictions no longer apply, with the exception of predictable twisting and turning type manoeuvres at speed, which was not formally introduced until 4 months after surgery, progressing to unrestricted agility from 5 months post-ACLR surgery. It is not until 6 months following ACL reconstruction that no physical restrictions are placed on the patients and full-contact sports are gradually introduced.

The experimental design was to ensure that the overall duration, volume, modes and intensity of exercise conditioning associated with PPM and CON rehabilitation groups were matched precisely. In addition to the clinical notes documenting each routine physiotherapy session, the dosing, volume, and intensity of rehabilitation were controlled by patients' self-monitoring of activities using structured weekly self-report diaries, with physiotherapist verification of dosing in formal and structured rehabilitation sessions.

7.3.4 - Experimental and assessment procedures

The detailed descriptions of apparatus and assessment procedures for this study can be found in General Methods **(Chapter 4**; see p. 162**)**. Documented below is a methodological summary to briefly outline the participants, experimental design, and approaches to the statistical testing of hypotheses used in this RCT.

The first assessment session included time for patients to become familiarised with the experimental and assessment procedures and protocols, and was devised to obtain baseline pre-surgery measures. During the initial meeting with the assessor (2 weeks prior to surgery) and at subsequent assessment sessions (conducted at 6 weeks, 12 weeks, and 48 weeks) following ACLR surgery, each patient was assessed by P-BOMs (VAS [Pain], IKDC [primary outcome measure], Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, EMD, RFD, and SMP-FE) for this study. In the latter, and contrary to contemporary clinical practice, this study evaluated the use of musculoskeletal (ATFD) and neuromuscular outcome measures (PF, EMD, RFD, and SMP-FE) to potentially understand the neuro-musculoskeletal and Sensorimotor Performance capabilities of patients during recovery and rehabilitation following

ACLR surgery (Gleeson et al., 1996, Gleeson et al., 2002; Minshull et al., 2007; Bailey et al., 2014; Bailey et al., 2015). The inclusion of C-BOMs: ATFD, PF, RFD, EMD and SMP-FE associated with the knee extensors and flexors of the injured and non-injured legs were further investigated, where possible.

Assessments procedure of P-BOM/C-BOM, and the order of testing limbs were undertaken in a random sequence (p. 169).

Prior to all testing, patients undertook a standardised warm-up protocol (p. 188).

7.3.1a - Single-Leg Hop for distance

Following two to three practice attempts, the patient hopped as far as possible starting on one leg and landing on the same leg. The distance was measured and the mean of 3 inter-trial replicates subsequently used for analysis (p. 190)

7.3.1b - Musculoskeletal outcome measure

Assessment of Anterior Tibio-Femoral Displacement (ATFD) was measured using a previously described method (p. 191).

7.3.1c - Neuromuscular outcome measures

A mean of 3 maximal volitional muscle activation was calculated for both the knee extensors and flexors in the injured and non-injured limbs as a measure of Peak Force (p. 195).

Electromyographic activity (EMG) was recorded and described in **Chapter 4** (General methods) (p. 189).

The Rate of Force Development (RFD) was calculated as the average rate of force increase between 25% and 75% of Peak Force (PF) (p. 198).

Electromechanical Delay (EMD) was computed as the time lag between the onset of muscle activity and the onset of force using the mean of 3 intra-trial muscle activations (p. 196).

Sensorimotor Performance (SMP) was measured by the Force Error (FE) arising from a task that required the 'blinded' replication using the knee flexors of a target force (50 % of pre-ACLR value of PF (p. 192).

7.4 - Statistical Analyses

The software that was utilised for the statistical analysis for the study was Statistical Package for Social Sciences (SPSS; version. 20.0). All descriptive statistics (mean and standard deviation) were presented for all variables (P-BOMs and C-BOMs), where appropriate.

It is necessary to determine if the PPM and CON rehabilitation groups demonstrated any significant differences amongst P-BOMs and C-BOMs, demographically-, anthropometrically-, and orthopaedically-relevant characteristics at pre-surgery. Baseline group mean comparisons were performed using separate one-way ANOVAs, involving independent groups (PPM and CON), on each dependent variable of interest. All variables (i.e., P-BOMs and C-BOMs) would be assessed to confirm normal distribution, and normality of all data variables (P-BOM: VAS [Pain], IKDC, KOOS, Lysholm, Performance Profile, and C-BOMs: Single-Leg Hop for distance, PF, EMD, RFD, ATFD, and SMP-FE) was evaluated separately for the experimental and control rehabilitation group. Normality of data in this trial was evaluated using Shapiro-Wilks (numerical test) and Q-Q plot (graphical test). These tests are designed for small to moderate sample sizes and have good power across a range of non-normal distribution.

The potential for using analysis of covariance (ANCOVA) to statistically control for influential variables that could not be controlled experimentally within the study design, had been considered. As musculoskeletal injury rehabilitation outcomes are reportedly determined by a variety of anthropometric characteristics, orthopaedic-associated factors (Holla et al., 2013; Vincent et al., 2006, Lohmander et al., 2004) as well as environment and dose of exercise (Riseberg, 2004, Renstrom et al., 2008; Hewett et al., 2006). An investigation into the influence of anthropometric and orthopaedic-related factors (as above) would be necessary to statistically assess whether they affected the relationships amongst P-BOMs and C-BOMs at pre-surgery and across all rehabilitation phases. Factors like waiting time for surgery, which could not be experimentally-controlled within this study's design, and other influences like patients' anthropometric characteristics and orthopaedically-relevant factors have been shown to correlate to these clinical outcomes (Holla et al., 2013, Vincent et al., 2006, Lohmander et al., 2004) and are important aspects to consider.

The effects of the PPM intervention in patients undergoing ACLR surgery was assessed for each variable (P-BOMs: VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile, and C-BOM: Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) using separate ANOVAs, involving factors of group (PPM; CON) by leg (injured/non-injured) by assessment occasions (Pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) with repeated measures on the latter two factors. The outcome performances associated with the knee extensors and flexors of both injured and non-injured legs were assessed separately, where appropriate.

A priori alpha levels were set at $p<0.05$. The experimental design offered an approximate 0.70 power of avoiding a type II error when employing a least detectable difference of 0.2 mm, 16N, 40N·s-1, 4ms, 2.5%, during comparisons of ATFD, PF, RFD, EMD, and SMP, scores over time, respectively (Lipsey, 1990). Where selected assumptions underpinning analysis of variance had not been met, Greenhouse-Geisser adjustments of the degrees of freedom associated with the experimental and error variances were used.

7.5 - Results

The studies outcome measures as appraised by P-BOMs[138] and C-BOMs[139] were evaluated separately. All descriptive statistics (mean and standard deviation) for the P-BOMs and C-BOMs are presented accordingly across assessment occasions (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) **(**see **APPENDIX 13**; p. 580**)**.

7.5.1 - Preliminary analysis at pre-surgery

It was further necessary to determine if the PPM and CON rehabilitation groups demonstrated any significant differences amongst P-BOMs and C-BOMs, demographically-, anthropometrically-, and orthopaedically-relevant characteristics at pre-surgery. Baseline group mean comparisons were performed using separate one-way ANOVAs, involving independent groups (PPM and CON), on each dependent variable of interest.

Analyses of group means for PPM and CON rehabilitation groups for P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile [in summary, $F_{(1,44}$ = 0.08 to 0.2; p > 0.05, *ns*]), C-BOMs (Single-Leg Hop for distance, ATFD, PF, EMD, RFD, and SMP-FE [in summary, $F_{(1,44}$ = 0.1 to 0.8; p > 0.05, *ns*]), together with anthropometric and orthopaedic-related factors (height [cm], body-mass [kg], time from injury to surgery [days], METs, and unstructured physical activity [strength, flexibility, and cardiovascular conditioning (time) [in summary, $F_{(1,44}$ = 0.4 to 1.7; p > 0.05, *ns*]) were shown to be statistically similar at pre-surgery (baseline). Only age at surgery proved to be an exception [$F_{(1, 44)}$ = 4.3; p< 0.04], with age of the PPM group (35.0 ± 14.2 years) being significantly greater than that of the CON group (27.6 ± 9.5 years). Although age at surgery showed significant differences between groups, correlational analyses showed age had no significant relationship with primary outcome variables (IKDC), other key P-BOMs and C-BOMs, either at pre-surgery (baseline) or during subsequent assessment occasions, and, suggesting that the wouldn't be influential in subsequent analyses.

7.5.2 - Changes in P-BOMs (VAS [Pain], IKDC, KOOS, Lysholm, and Performance Profile) and C-BOMs (Single-Leg Hop for Distance, ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery, and 6, 12, and 24 weeks post-ACLR surgery

[138] The VAS (Pain), IKDC, and Lysholm consisted of a total/aggregated score, while the KOOS consisted of five sub-domain scores (i.e., Symptoms, Pain, Function, Sport and Recreation, and Quality of life). The Performance Profile was the sole P-BOM that requested patients to rate each injured and non-injured leg separately.

[139] Similarly, Single-Leg Hop for distance ATFD, PF, EMD, RFD, and SMP-FE were computed for the knee flexors and knee extensors of the injured and non-injured limbs, where appropriate.

7.5.2.1 - Patient-Based Outcome Measures

7.5.2.1a - International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form (primary outcome measure)

Descriptive statistics (mean and standard deviation) for the IKDC are presented in **APPENDIX 13 (**p. 580**).** Analysis of variance (ANOVA) with repeated measures showed non-significant group (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for IKDC (primary outcome measure). The group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effect on IKDC scores overtime (PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (61.5 ± 10.0 versus 86.6 ± 11.8) (40.8% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (64.5 ± 12.8 versus 86.3 ± 6.4) (33.8% gain in performance) with no rehabilitation group indicating superiority in gaining performance capability [$F_{(2.1, 92.0)GG}$= 0.5; *ns*] (**FIGURE 35**; p. 332**)**.

7.5.2.1b - Performance Profile

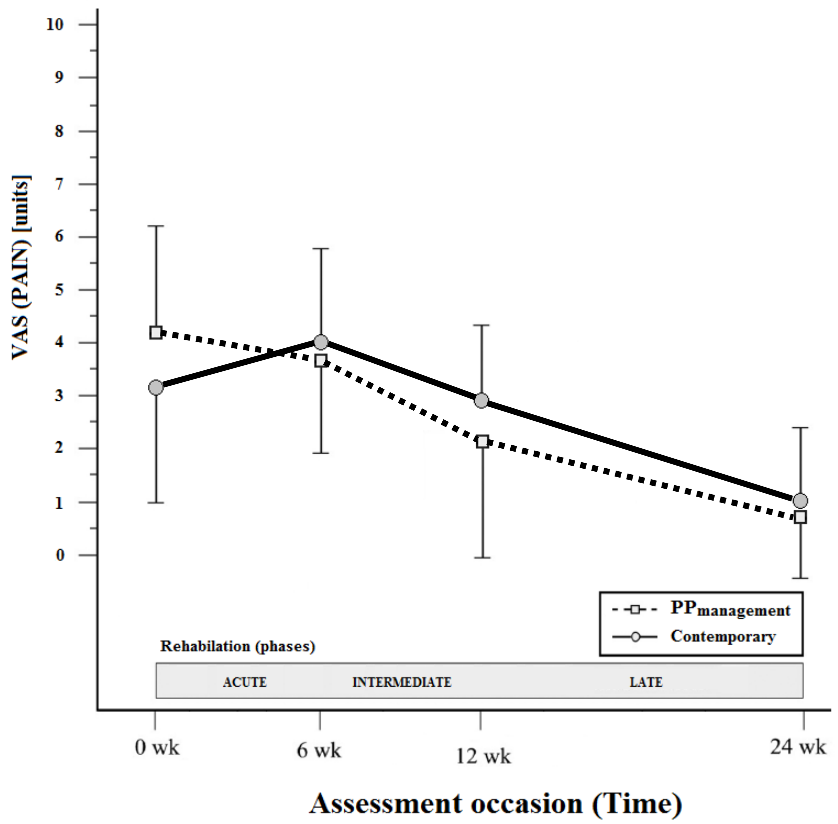
Descriptive statistics (mean and standard deviation) for the Performance Profile for the injured and non-injured limbs is presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for the Performance Profile for the injured and non-injured limbs. The group mean scores associated with injured limb for the PPM and CON rehabilitation groups demonstrated congruency of effect on Performance Profile (injured leg) scores over time (PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (4.3 ± 0.8 versus 9.1 ± 0.5) (111.6% gain in performance); CON: pre-surgery versus 24 weeks post-ACLR surgery (4.2 ± 0.9 versus 9.2 ± 0.3) (119.0% gain in performance) with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(3,87)}$= 0.4; *ns*] **(FIGURE 37**; p. 332**)**.

Similarly, the group mean scores associated with non-injured limb for the PPM and CON rehabilitation groups remained relatively constant (PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (9.4 ± 0.5 versus 9.8 ± 0.4) (4.3% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (9.5 ± 0.2 versus 9.8 ± 0.3) (3.2% gain in performance) throughout all assessment occasions with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(3, 87)}$ = 0.5; *ns*] **(FIGURE 37**; p. 332**)**.

Despite the lack of a significant three-way interactions (as above), further two-way ANOVA revealed a significant leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction [$F_{(3, 7.3)}$ = 216.8; $p< 0.05$]. This suggested that the injured and non-injured legs evaluated by respective Performance Profiles, irrespective of PPM and CON rehabilitation groups were significantly different overtime.

For the remaining P-BOMs (VAS [Pain] [$F_{(1.1,50.2)} = 1.1$; *ns*], Lysholm [$F_{(2.5,110.2)GG} = 0.29$; *ns*], and KOOS subscales [Symptoms: $F_{(3,132)} = 0.9$; *ns*; Pain: $F_{(3,132)} = 0.5$; *ns*; Function: $F_{(3,132)} = 0.7$; *ns*; Sport/rec: $F_{(3,132)} = 0.3$; *ns*; and QoL: $F_{(3,132)} = 0.9$; *ns*], all ANOVAs with repeated measures showed non-significant group (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction, with no rehabilitation group indicating superiority in gaining performance capability for any of the P-BOMs. Therefore, the remaining results of ANOVAs for all C-BOMs (VAS [Pain], Lysholm, and KOOS subscale)] are presented in **APPENDIX 15** (p. 590).

FIGURE 34 -
VAS (Pain) score changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.



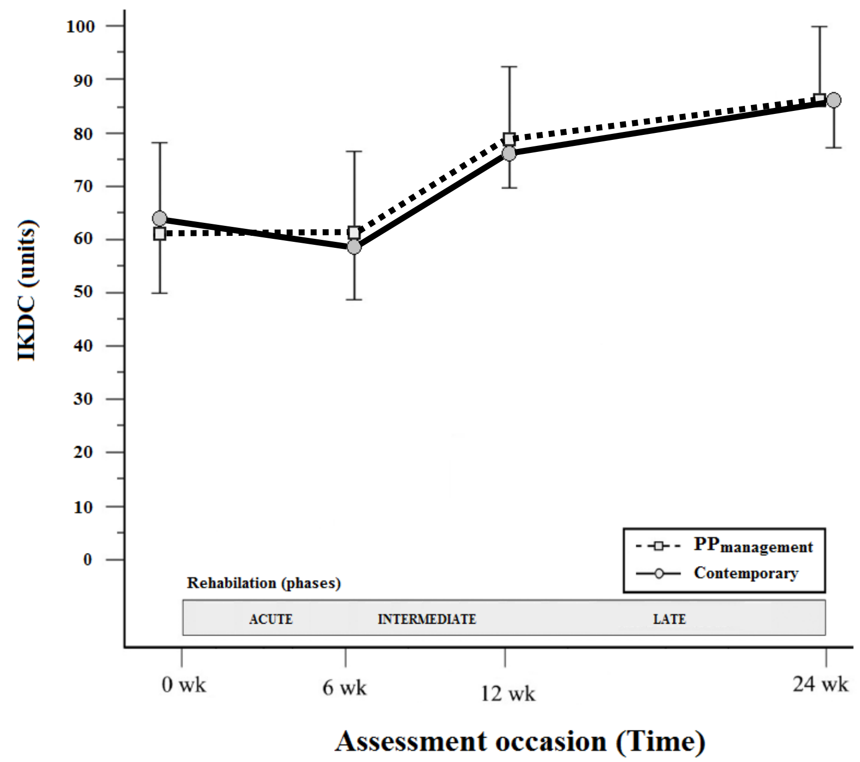
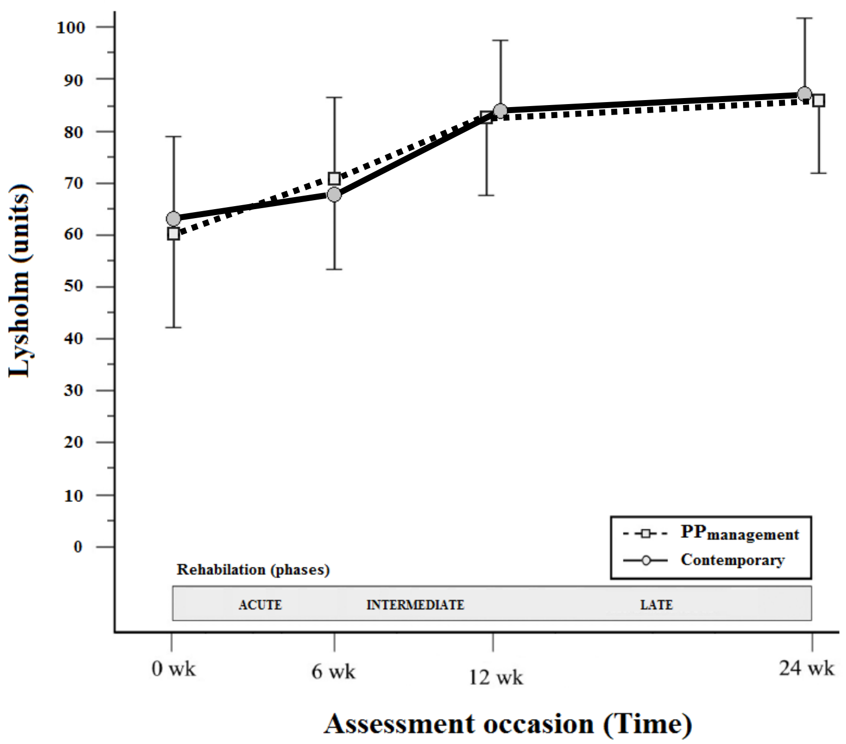


FIGURE 35 -
IKDC score changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.

FIGURE 36 -
Lysholm score changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.



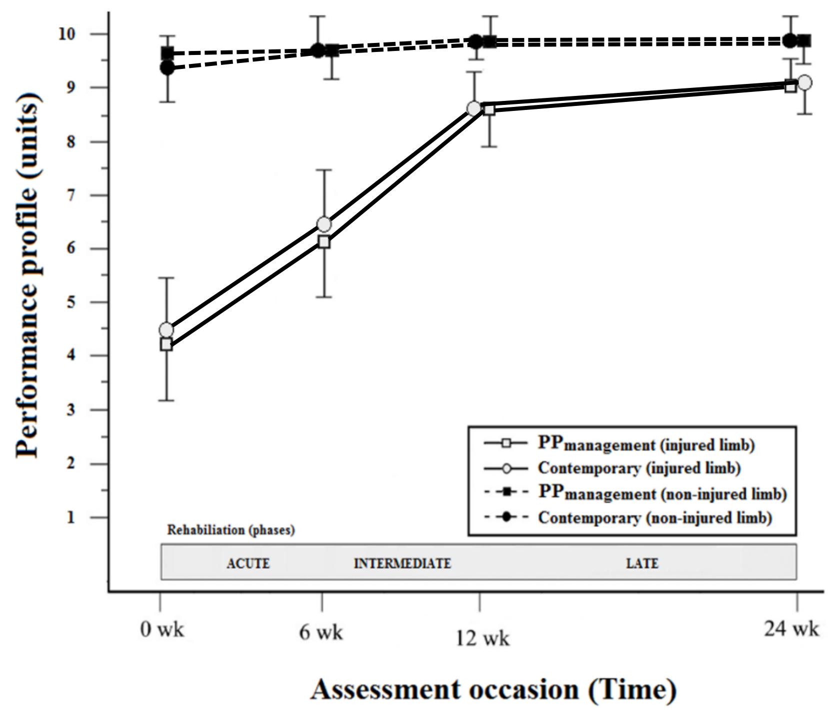


FIGURE 37 -
Performance Profile for injured and non-injured limbs changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups.

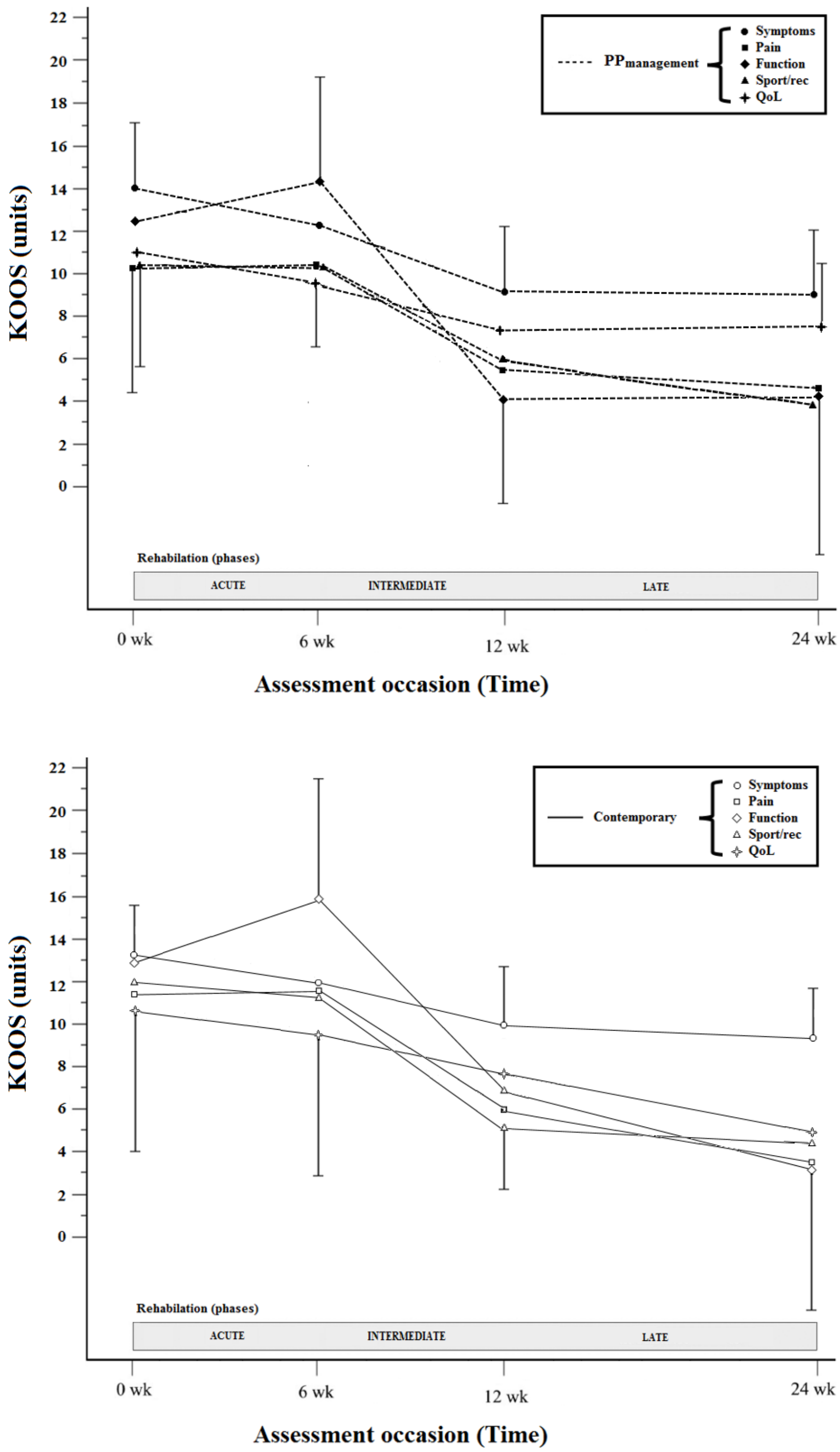


FIGURE 38 - KOOS subscales (Symptoms, Pain, Function, Sport/Rec, and QoL) score changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the Performance Profile management (PPM: upper figure) and contemporary (CON: lower figure) rehabilitation groups. **NOTE:** standard deviations for some of the PPM group and CON values were omitted and reported similar magnitudes **(**see **APPENDIX 13 [**p. 580]**)** for these omitted standard deviations values**)**.

7.5.2.2 - Clinician-Based Outcome Measures

7.5.2.2a - Single-Leg Hop for distance

Descriptive statistics (mean and standard deviation) for the Single-Leg-Hop for Distance is presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for Single-Leg-Hop for distance (injured leg outcome at 6 weeks post-ACLR surgery were not acquired as clinically contraindicated and corresponding data was not available for analyses). The group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effect on Single-Leg Hop for distance overtime with no rehabilitation group indicating superiority in gaining performance capability [$F_{(2,88)}$= 1.0; ns] **(FIGURE 39;** p. 336**).**

With regards to the non-injured limb, and unexpected, a two-factor ANOVA (leg [injured/non-injured] by assessment occasion [pre-surgery, 6, 12, and 24 weeks post-ACLR surgery]) was also non-significant [$F_{(2, 88)}$ = 0.1; *ns*], suggesting perhaps (given a priori expectations of greater gains in the injured leg over time), the performance of the 'control leg' (non-injured limb) was improving at the same rate as that of the injured leg.

Despite the lack of a significant three-way interactions (as above), further two-way ANOVA revealed a significant leg (injured; non-injured) by rehabilitation group (PPM; CON) interaction [$F_{(1, 44)}$ =4.4; $p< 0.05$]. This suggested that the Single-Leg Hop for distance evaluated by the injured and non-injured legs irrespective of assessment occasion were significantly different among the PPM and CON rehabilitation groups. Furthermore, differential in performance between injured and non-injured legs for Single-Leg Hop for distance, irrespective of assessment occasion, was significantly less for the PPM rehabilitation group (9.5 cm [pooled group mean ± SD for injured and non-injured legs at pre-ACLR surgery, 12, and 24 weeks assessment occasions] (126.1 ± 28.7 versus 135.6 ± 34.6)] than for the CON rehabilitation group (18.7 cm (111.5 ± 19.3 versus 130.2 ± 19.2]), respectively.

7.5.2.2b - Sensorimotor Performance

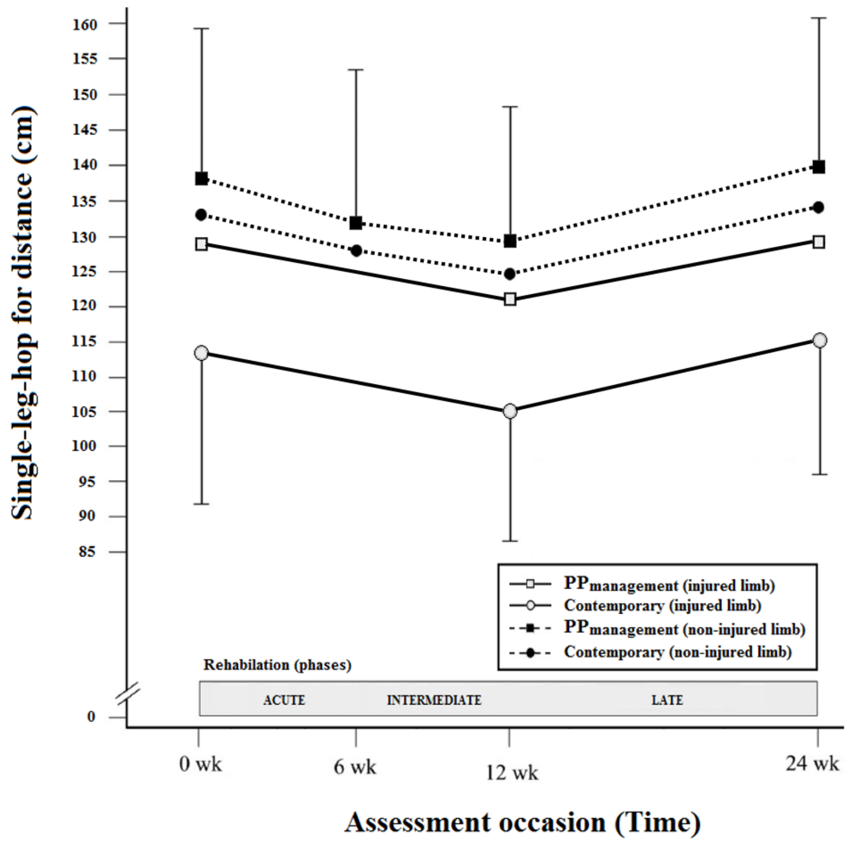
Descriptive statistics (mean and standard deviation) for the SMP-FE with the injured and non-injured limbs are presented in **APPENDIX 13** (p. 580) associated with the knee flexors and knee extensor musculature. Analysis of variance (ANOVA) with repeated measures showed significant group (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for SMP-FE for the knee extensors [$F_{(2.5, 113.7)GG}$= 3.2; $p< 0.05$]. However, with regards to the knee flexors using the same ANOVA, a non-significant interaction was found [$F_{(2.2, 100.4)GG}$= 1.5; *ns*] **(**see **FIGURE 42**).

The group mean scores associated with the knee extensors for the PPM and CON rehabilitation groups demonstrated congruency of effect on SMP-FE scores over time (PPM: pre-surgery versus 24 weeks post-ACLR surgery (186.2 ± 64.3 versus 185.1 ± 62.1) (1.2% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (186.0 ± 68.8 versus 188.3 ± 68.0) (-0.6% loss in performance) with no rehabilitation group indicating superiority in gaining performance capability [$F_{(1.6,73.3)GG}$= 0.3; ns] **(**see **FIGURE 43).**

Similarly, the absence of an interaction associated with knee flexors between all three factors suggested that while patterns of improvement in SMP-FE over time were dependent, separately, on which leg was being assessed and under which regime of rehabilitation group condition had taken place, the extent of rehabilitation regime-related difference in SMP-FE of the injured and non-injured legs remained at a similar level across the period of study. The latter was therefore characterised by progressive improvements in performance, but was not influenced exceptionally by particular phases of the rehabilitation groups. The patterns of SMP-FE responses for the knee flexor musculature were similar (PPM: pre-ACLR surgery versus 24-week post-ACLR surgery (110.1 ± 30.7 versus 110.4 ± 31.4) (-0.1% loss in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (108.1 ± 39.1 versus 108.0 ± 39.6) (0.3% gain in performance) with significant leg by assessment occasion with no rehabilitation group condition indicating superiority in gaining performance capability.

For the remaining C-BOMs (ATFD, PF, RFD, and EMD) all ANOVAs with repeated measures showed non-significant group (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction with no rehabilitation group indicating superiority in gaining performance capability for any of the C-BOMs (as above). Therefore, the remaining results of ANOVAs for all C-BOMs are presented in **APPENDIX 15**.

FIGURE 39 -
Single-Leg Hop for distance scores for injured limbs changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups. **<u>NOTE</u>:** standard deviations for PPM (injured limb) and contemporary (non-injured limb) were omitted and reported similar magnitudes **(**see **APPENDIX 13** (p. 580) for these omitted standard deviations**)**.



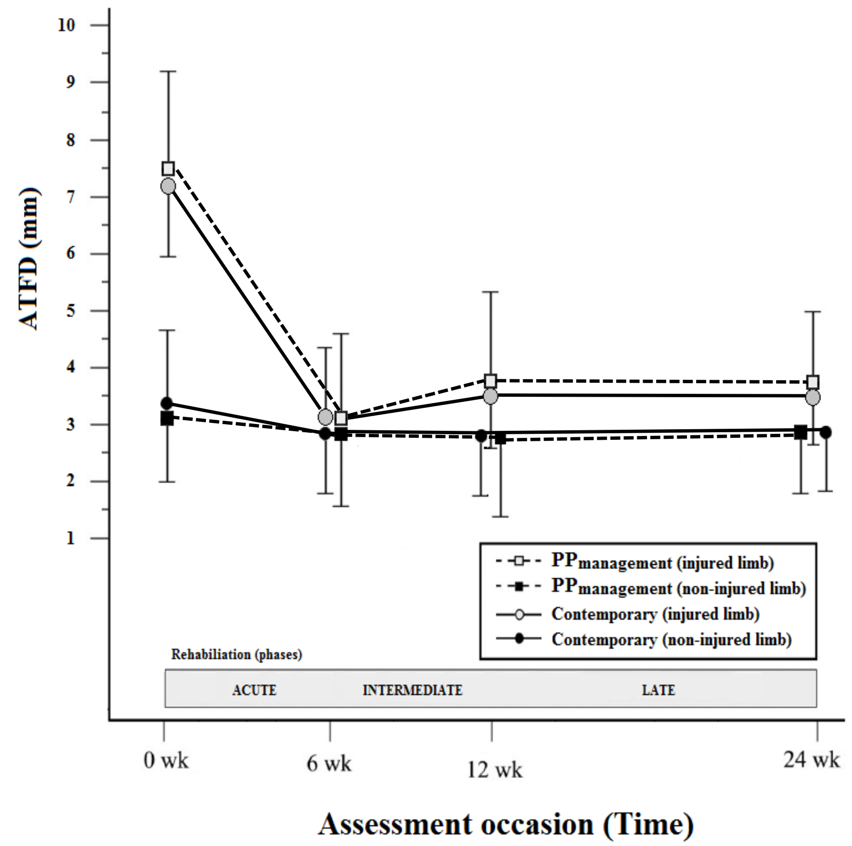
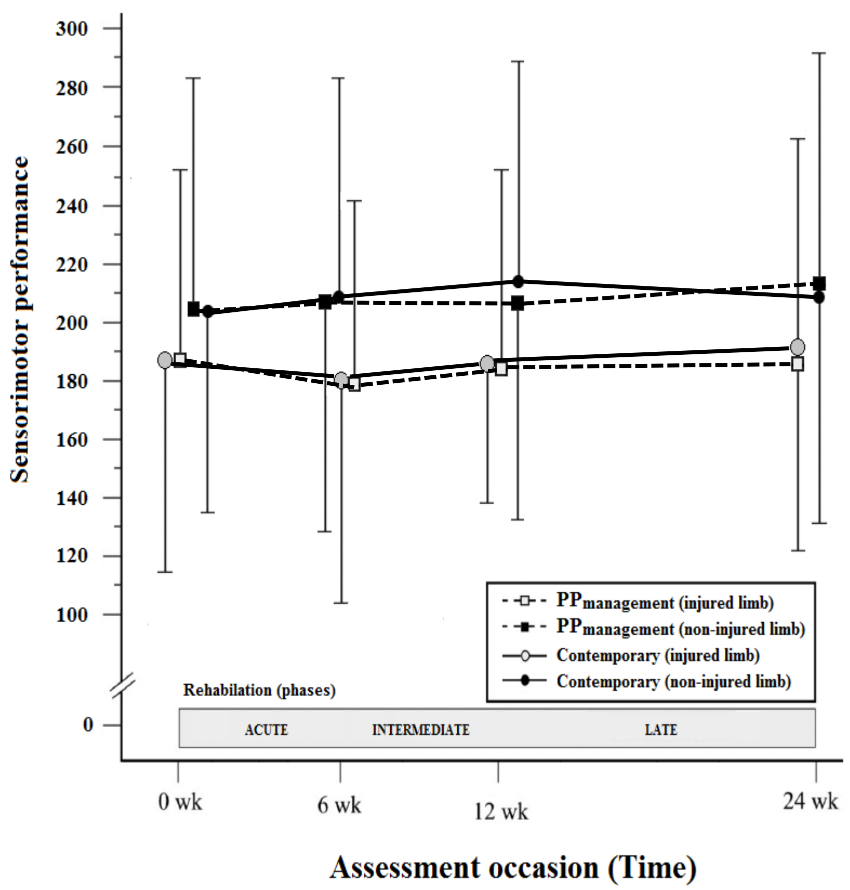


FIGURE 40 -
Sensorimotor Performance associated with Force Error (SMP-FE) scores with injured and non-injured limb associated with knee extensors changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.

FIGURE 41 -
Sensorimotor Performance associated with Force Error (SMP-FE) scores with injured and non-injured limb associated with knee extensors changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.



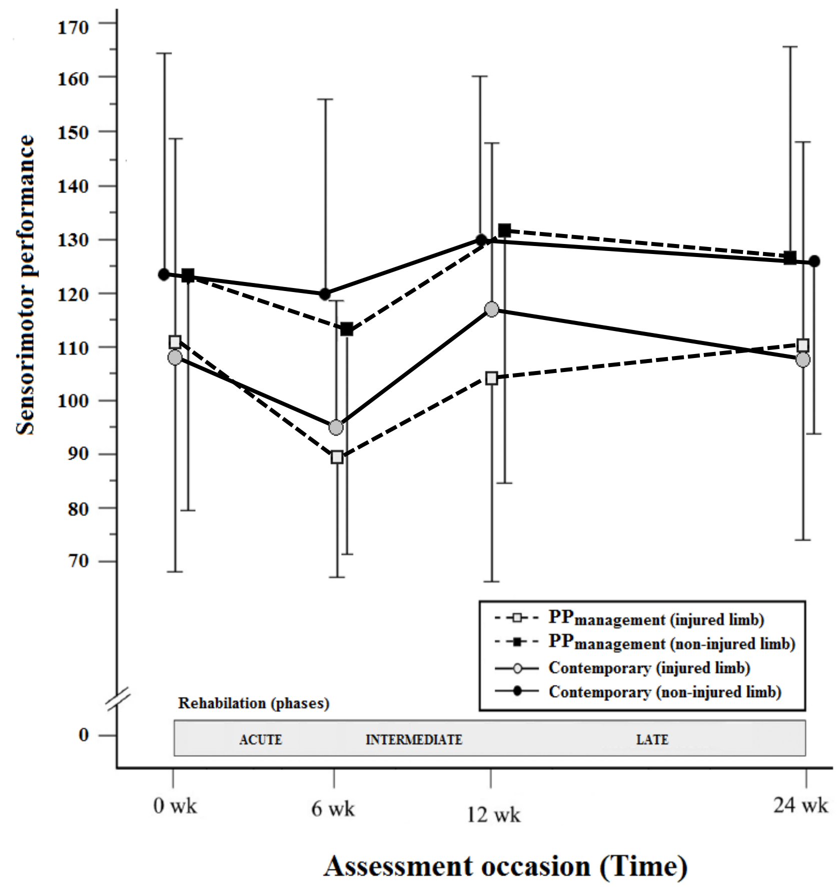
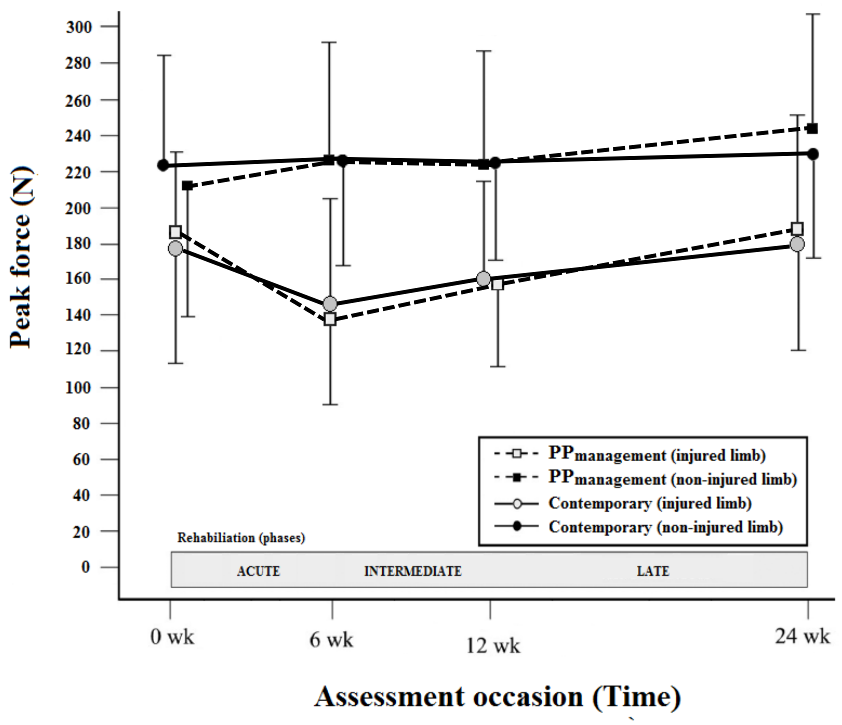


FIGURE 42 -
Sensorimotor Performance associated with Force Error (SMP-FE) scores with injured and non-injured limb associated with knee flexors changes following ACLR surgery from pre-surgery, 6, 12, and 24 weeks post-ACLR surgery for the PPM and CON rehabilitation groups.

FIGURE 43 -
Peak Force (PF) scores for injured and non-injured limbs associated with the knee flexors between PPM and CON rehabilitation groups evaluated at pre-surgery, 6, 12, and 24 weeks post-ACLR surgery.



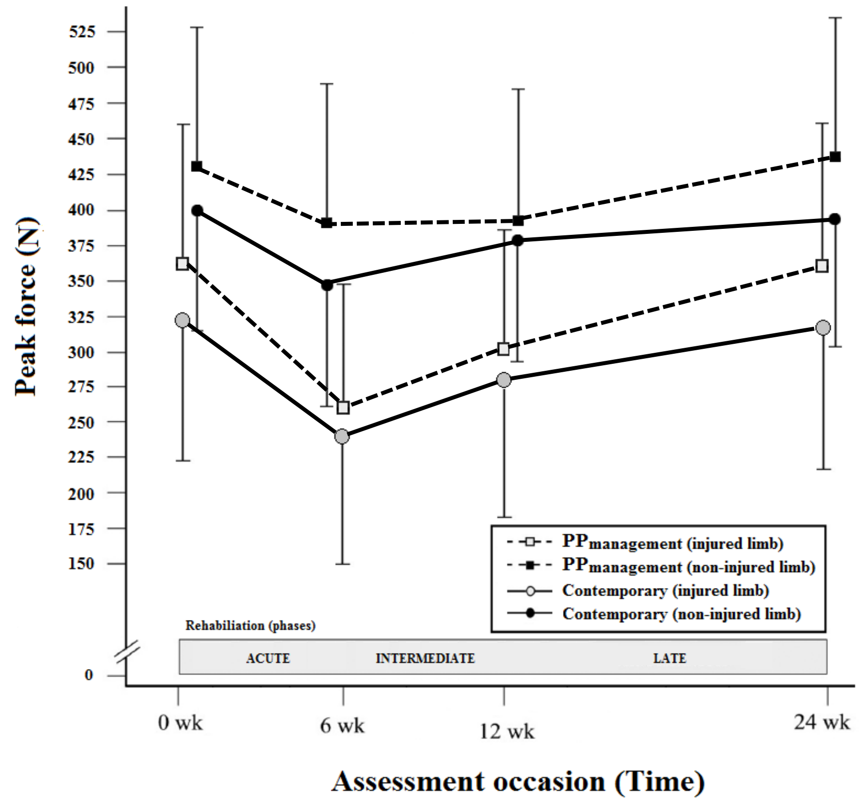
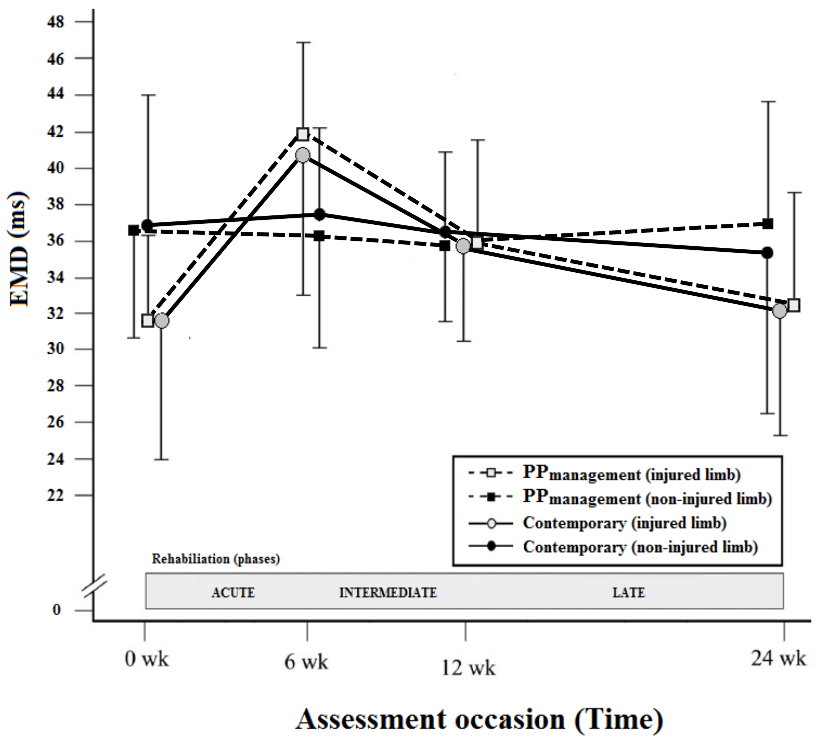


FIGURE 44 -
Peak force (PF) scores for injured and non-injured limbs associated with the knee extensors between PPM and CON rehabilitation groups evaluated at pre-surgery, 6, 12, and 24 weeks post-ACLR surgery.

FIGURE 45 -
EMD scores for injured and non-injured limbs associated with the knee extensors between PPM and CON rehabilitation groups evaluated at pre-surgery, 6, 12, and 24 weeks post-ACLR surgery.



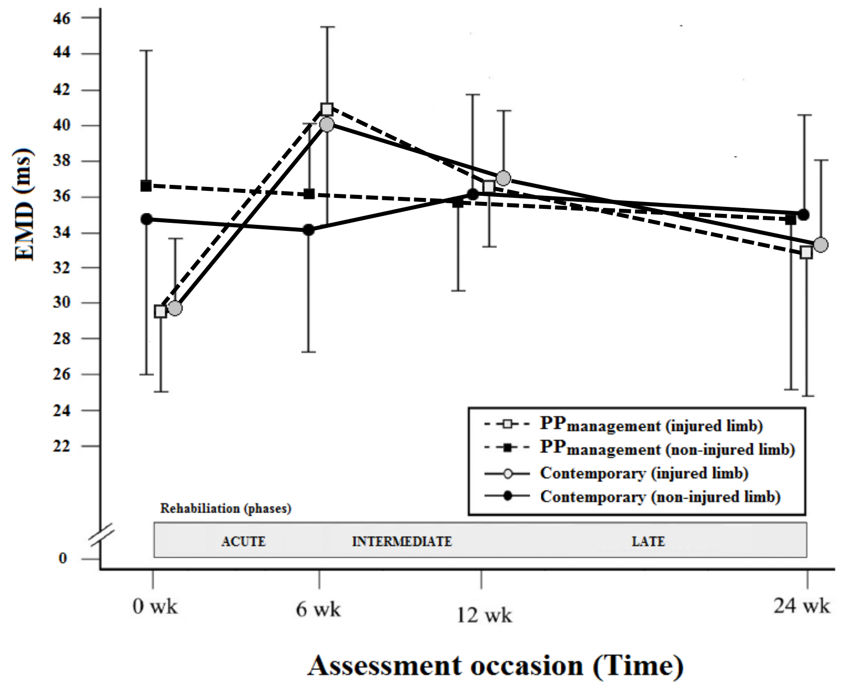


FIGURE 46 -
EMD scores for injured and non-injured limbs associated with the knee flexors between PPM and CON rehabilitation groups evaluated at pre-surgery, 6, 12, and 24 weeks post-ACLR surgery.

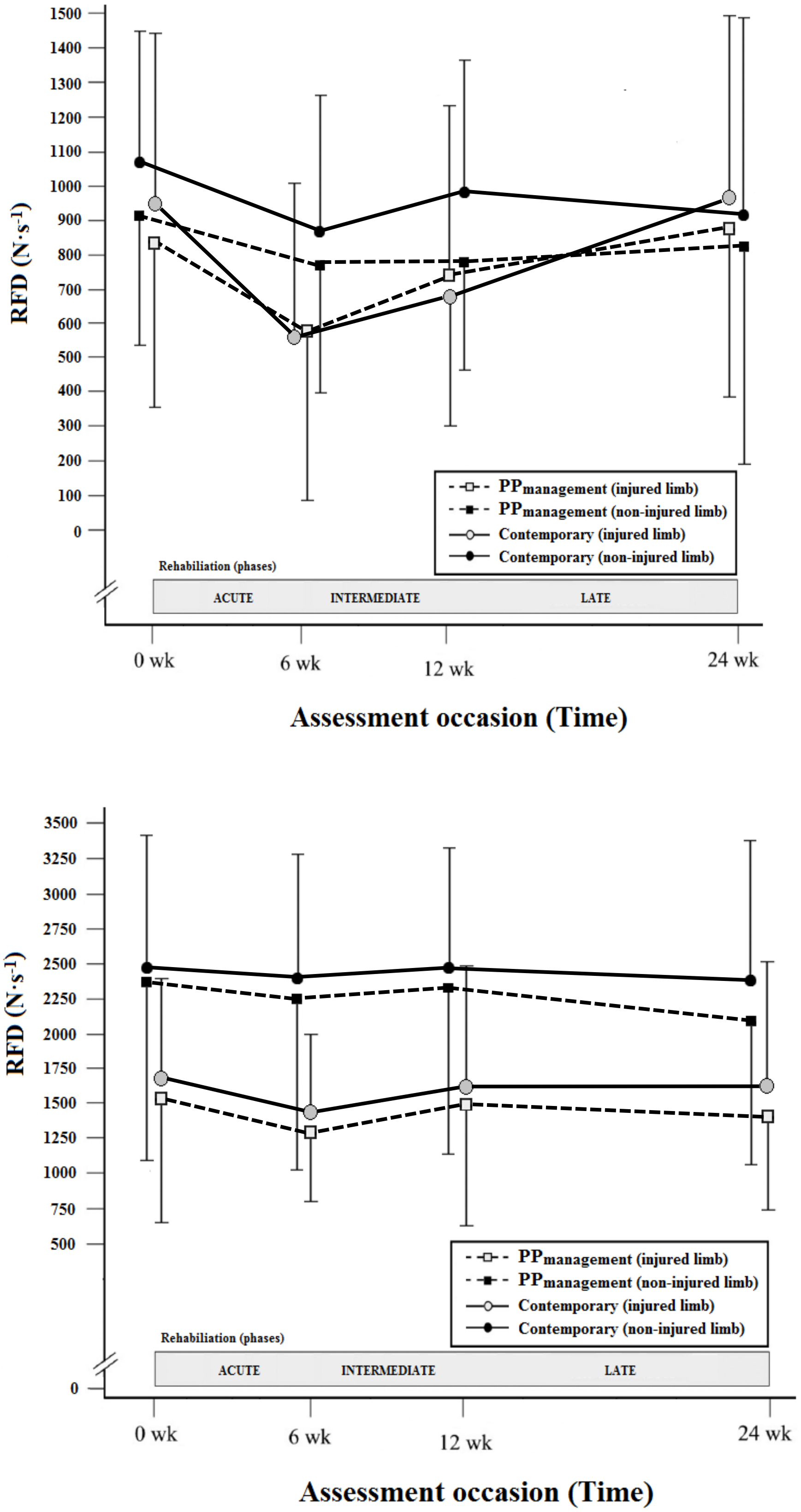


FIGURE 47 - RFD scores for injured and non-injured limbs associated with the knee flexors (top figure) and knee extensors (bottom figure) between PPM and CON rehabilitation groups evaluated at pre-surgery, 6, 12, and 24 weeks post-ACLR surgery.

7.5.2.3 - Evaluation of the interaction effects ($p < 0.05$) of P-BOMs and C-BOMs at pre-ACLR surgery (baseline) versus the acute, intermediate and late phases of rehabilitation for PPM and CON rehabilitation groups, respectively

All of the P-BOMs (VAS [Pain], IKDC, KOOS (sub-scale scores), Lysholm, and Performance Profile [injured and non-injured limbs]) alongside the C-BOMs (ATFD, PF, EMD, RFD, and SMP-FE (knee flexors only)) found that each computed ANOVA's with repeated measures indicated no-significant interaction for rehabilitation groups (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) for P-BOM/C-BOM. Therefore, for all P-BOMs and C-BOMs, the group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effects overtime with no rehabilitation group condition indicating superiority in gaining performance capabilities. However, with this said, for P-BOM and C-BOM outcomes all reporting non-significant ANOVA's interactions by respective ANOVAs, and given that no influence of rehabilitation groups was found, data from PPM and CON rehabilitation groups were pooled to allow comparison over time irrespective of rehabilitation group performances. Therefore, without group differentiation allowing comparison of patterning of P-BOM and C-BOM outcomes over time for the PPM and CON rehabilitation groups, the secondary question of congruency among P-BOMs and C-BOMs over time, irrespective of rehabilitation groups were to be addressed for each P-BOMs and C-BOMs.

7.5.2.3.1 - Patient-Based Outcome Measures

7.5.2.3.1a - VAS (Pain)

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in VAS (Pain) scores (maximum score, 10) suggested that the effects of rehabilitation between PPM and CON rehabilitation group conditions at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (4.1 ± 1.9 versus 3.1 ± 2.0 units; 2.1 ± 2.0 versus 2.9 ± 1.3 units) and 24 weeks post-ACLR surgery (4.1 ± 1.9 versus 3.1 ± 2.0 units; 0.7 ± 1.0 versus 1.0 ± 1.2 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation group conditions, respectively, of -48.8% and -6.5% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and -82.9% and -67.7% for pre-ACLR surgery versus 24 weeks post-ACLR surgery, respectively[140] [$F(2.1, 91.9)_{GG} = 51.4$; $p < 0.05$] **(TABLE 61**; p. 342**)**.

[140] Percentage (%) change scores from pre-ACLR surgery (baseline) versus 6-, 12-, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for P-BOMs.

7.5.2.3.1b - International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in IKDC scores (maximum score, 100) suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (64.5 ± 12.8 versus 76.7 ± 5.6 units; 61.5 ± 10.0 versus 78.2 ± 11.9 units) and 24 weeks post-ACLR surgery (61.5 ± 10.0 versus 86.6 ± 11.8 units; 64.5 ± 12.8 versus 86.3 ± 6.4 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, of 27.2% and 40.8% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 18.9% and 33.8% for pre-surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(2.1,\ 91.9)GG} = 51.4$; $p< 0.005$]) **(TABLE 61**; p. 342**)**.

7.5.2.3.1c - Lysholm (Lysholm) Knee Score

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in Lysholm scores (maximum score, 100) suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (60.6 ± 15.8 versus 70.3 ± 14.5 units; 62.5 ± 14.2 versus 67.7 ± 12.7 units), 12 weeks post-ACLR surgery (60.6 ± 15.8 versus 83.4 ± 13.9 units; 62.5 ± 14.2 versus 84.4 ± 11.8 units),and 24 weeks post-ACLR surgery (60.6 ± 15.8 versus 86.4 ± 13.6 units; 62.5 ± 14.2 versus 87.6 ± 12.4 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of 16.0% and 8.3% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of 37.6% and 35.0% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 42.6% and 40.2% for pre-ACLR surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(2.5,110.2)GG} = 41.3$; $p<0.005$] **(TABLE 61**; p. 342**)**.

7.5.2.3.1d - KOOS sub-scale scores

Testing of an *a priori*' difference' hypothesis of greater progressive increases in KOOS sub-scale (Symptoms) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (14.0 ± 3.2 versus 12.1 ± 2.5 units; 13.0 ± 3.7 versus 12.1 ± 2.8 units), 12 weeks post-ACLR surgery (14.0 ± 3.2 versus 9.4 ± 2.4 units; 13.0 ± 3.7 versus 9.9 ± 2.5 units), and 24 weeks post-ACLR surgery (14.0 ± 3.2 versus 9.2 ± 2.3 units; 13.0 ± 3.7 versus 9.1 ± 2.1 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of 13.6% and 6.9% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of 32.9% and 23.8% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 34.3% and 30.0% for pre-ACLR surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(2.5,110.2)GG} = 41.3$; $p < 0.005$] **(TABLE 61**; p. 342**)**.[141]

7.5.2.3.1e - Performance Profile

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in Performance Profile scores (maximum score, 10) suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (4.3 ± 0.8 versus 6.4 ± 0.9 units; 4.2 ± 0.9 versus 6.3 ± 1.0 units), 12 weeks post-ACLR surgery (4.3 ± 0.8 versus 8.6 ± 0.7 units; 4.2 ± 0.9 versus 8.6 ± 0.7 units), and 24 weeks post-ACLR surgery (4.3 ± 0.8 versus 9.1 ± 0.5 units; 4.2 ± 0.9 versus 9.2 ± 0.3 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of 48.8% and 50.0% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of 100.0% and 104.8% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 111.6% and 119.0% for pre-ACLR surgery versus 24 weeks post-ACLR surgery **(TABLE 61**; p. 342**)**.

[141] Testing of an *a priori* 'difference' hypothesis of greater progressive increases in KOOS sub-scales scores suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery and 24 weeks post-ACLR surgery contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, for Pain, Function, Sport/rec, and QoL.

TABLE 61 - Percentage (%) change scores from pre-surgery (baseline) versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for P-BOMs. Results presented as either negative or positive change scores from pre-surgery (mean scores) versus each assessment occasion. All highlighted values indicate significant interaction ($p < 0.05$). **NOTE:** All P-BOMs other than Performance Profile evaluated injured and non-injured limbs separately.

PBOM (WITH COMPONENT SCORE).	INJURED/ NON-INJURED LIMBS.	REHABILITATION GROUP CONDITION.	ASSESSMENT OCCASION (pre-surgery, 6, 12, and 24 weeks post-surgery).				
					6-WEEKS	12-WEEKS	24-WEEKS
VAS (pain)		PPM. CON.	Pre-surgery (baseline)	vs.		-48.8% -6.5%	-82.9% -67.7%
IKDC		PPM. CON.	Pre-surgery (baseline)	vs.		27.2% 18.9%	40.8% 33.8%
Lysholm		PPM. CON.	Pre-surgery (baseline)	vs.	16.0% 8.3%	37.6% 35.0%	42.6% 40.2%
KOOS	KOOS (symptoms)	PPM. CON.	Pre-surgery (baseline)	vs.	-13.6% -6.9%	-32.9% -23.8%	-34.3% -30.0%
	KOOS (Pain)	PPM. CON.	Pre-surgery (baseline)	vs.		-48.5% -47.2%	-57.4% -66.0%
	KOOS (Function)	PPM. CON.	Pre-surgery (baseline).	vs		-67.5% -58.9%	-65.9% -74.4%
	KOOS (Sport/rec)	PPM. CON.	Pre-surgery (baseline)	vs.		-41.7% -42.5%	-63.1% -64.2%
	KOOS (QoL)	PPM. CON.	Pre-surgery (baseline)	vs.		-35.5% -27.6%	-34.5% -59.0%
Performance Profile	Injured Injured	PPM. CON.	Pre-surgery (baseline)	vs.	48.8% 50.0%	100.0% 104.8%	111.6% 119.0%
	Non-injured Non-injured	PPM. CON.	Pre-surgery (baseline)	vs.	2.1% 1.1%	4.3% 3.2%	4.3% 3.2%

7.5.2.3.3 - Clinician-Based Outcome Measures

7.5.2.3.3a - Single-Leg Hop for distance

Testing of an *a priori* ‘difference’ hypothesis of greater progressive increases in Single-Leg-Hop score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (128.1 ± 27.4 versus 113.6 ± 20.5 units; 121.2 ± 29.0 versus 105.1 ± 18.2 units) contributed to significant interaction at the intermediate phase of rehabilitation only. In the latter, the PPM and CON rehabilitation groups accounted for -5.4% and -7.5%, respectively, for pre-ACLR surgery versus 12 weeks post-ACLR surgery [$F_{(3,132)} = 3.2$; $p < 0.05$]) (**TABLE 62**; p. 345).

7.5.2.3.3b - Anterior Tibio-Femoral Displacement (ATFD)

Testing of an *a priori* ‘difference’ hypothesis of greater progressive increases in ATFD score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (7.4 ± 1.5 versus 3.0 ± 1.5 units; 7.2 ± 1.2 versus 3.0 ± 1.1 units), 12 weeks post-ACLR surgery (7.4 ± 1.5 versus 3.7 ± 1.2 units; 7.2 ± 1.2 versus 3.5 ± 0.7 units),and 24 weeks post-ACLR surgery (7.4 ± 1.5 versus 3.7 ± 1.2 units; 7.2 ± 1.2 versus 3.5 ± 0.6 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of 59.5% and 58.3% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of 50.0% and 51.4% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 50.0% and 51.4% for pre-surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(1.6,73.3)GG} = 100.9$; $p < 0.05$] (**TABLE 62**; p. 345).

7.5.2.3.3c - Sensorimotor Performance

Testing of an *a priori* ‘difference’ hypothesis of greater progressive increases in SMP-FE score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (186.2 ± 64.3 versus 176.0 ± 62.6 units; 186.0 ± 68.8 versus 178.8 ± 71.8 units) contributed to significant interaction at the acute phase of rehabilitation only. In the latter, the PPM and CON rehabilitation groups accounted for -5.5% and 3.9%, respectively, for pre-ACLR surgery versus 6 weeks post-ACLR surgery [$F_{(3,132)} = 3.2$; $p < 0.05$]) (**TABLE 62**; p. 345).

7.5.2.3.3d - Peak Force (PF)

Testing of an *a priori* ‘difference’ hypothesis of greater progressive increases in PF (knee flexors of the injured limb) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (183.6 ± 41.8 versus 180.1 ± 60.5 units; 139.8 ± 41.4 versus 145.6 ± 57.8 units), 12 weeks post-ACLR surgery (183.6 ± 41.8 versus 180.1 ± 60.5 units; 158.2 ± 39.6 versus 160.6 ± 52.2 units), and 24 weeks post-ACLR surgery (183.6 ± 41.8 versus 180.1 ± 60.5 units; 187.4 ± 60.5 versus 179.2 ± 56.3 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of -23.9% and -19.2% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of -13.8% and -10.8% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 2.1% and -0.5% for pre-surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(1.6,73.3)GG}$= 100.9; $p< 0.05$]. Moreover, for the knee extensors (injured and non-injured limbs) similar responses were found, however, no significant interactions were found at the intermediate phase of rehabilitation **(TABLE 63**; p. 346**)**.

7.5.2.3.3e - Rate of Force Development (RFD)

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in RFD (knee extensors of the injured limb) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 24 weeks post-ACLR surgery (1514.6 ± 835.5 versus 1682.2 ± 651.4 units; 1421.9 ± 613.9 versus 1620.8 ± 690.1 units) contributed to significant interaction at the late phase of rehabilitation only. In the latter, the PPM and CON rehabilitation groups accounted for -6.1% and -3.6%, respectively, for pre-ACLR surgery versus 24 weeks post-ACLR surgery [$F_{(3,132)}$ = 3.2; $p< 0.05$]). Moreover, for the knee extensors of the non-injured limb similar responses were found **(TABLE 63**; p. 346**)**[142].

7.5.2.3.3f - Electromechanical Delay (EMD)

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in EMD (knee flexors of the injured limb) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 6 weeks post-ACLR surgery (29.5 ± 3.9 versus 29.8 ± 3.5 units; 40.9 ± 4.1 versus 39.9 ± 4.9 units), 12 weeks post-ACLR surgery (29.5 ± 3.9 versus 29.8 ± 3.5 units; 36.4 ± 3.1 versus 37.1 ± 3.4 units), and 24 weeks post-ACLR surgery (29.5 ± 3.9 versus 29.8 ± 3.5 units; 32.8 ± 7.9 versus 33.5 ± 4.2 units) all contributed to significant interaction across all phases of rehabilitation, and gains for the PPM and CON rehabilitation groups, respectively, of -19.0% and -12.1% for pre-ACLR surgery versus 6 weeks post-ACLR surgery, of -5.0% and 8.6% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 0.3% and -0.1% for pre-surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(1.6,73.3)GG}$= 100.9; $p< 0.05$]. Moreover, for the knee flexors of the non-injured limb similar responses were found **(TABLE 64**; p. 347**)**[143].

[142] RFD: No significant interactions were found for the knee flexors associated with both the injured and non-injured limbs at the acute, intermediate, or late phases of rehabilitation.

[143] EMD: For the knee extensors for the injured and non-injured limbs, similar interactions were found for the acute and late phases of rehabilitation only.

TABLE 62 - Percentage (%) change scores from pre-ACLR surgery (baseline) versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for C-BOMs (Single-Leg Hop for distance, ATFD, and SMP-FE). Results presented as either negative or positive change scores from pre-surgery (mean scores) versus each assessment occasion. Highlighted values indicate significant ($p < 0.05$) interaction. **<u>NOTE</u>:** All C-BOMs were evaluated injured and non-injured limbs associated with the knee flexors and knee extensor musculature separately.

CLIN-BOM.	MUSCULATURE ASSESSED (KNEE FLEXOR or EXTENSORS).	INJURED / NON-INJURED LIMBS.	REHABILITATION GROUP CONDITION.	ASSESSMENT OCCASION: (PRE-SURGERY, 6, 12, AND 24-WEEKS POST-SURGERY).				
						6-WEEKS	**12-WEEKS**	**24-WEEKS**
HOP		Injured	PPM.	**Pre-surgery**	vs.		**-5.4%**	
		Injured	CON.	(baseline)			**-7.5%**	
		Non-injured	PPM.	**Pre-surgery**	vs.		**-6.0%**	
		Non-injured	CON.	(baseline)			**-5.5%**	
ATFD		Injured	PPM.	**Pre-surgery**	vs.	**-59.5%**	**-50.0%**	**-50.0%**
		Injured	CON.	(baseline)		**-58.3%**	**-51.4%**	**-51.4%**
		Non-injured	PPM.	**Pre-surgery**	vs.	**-6.3%**	**-12.5%**	**-9.4%**
		Non-injured	CON.	(baseline)		**-14.7%**	**-14.7%**	**-14.7%**
SMP-FE	Flexors	Injured	PPM.	**Pre-surgery**	vs.			
		Injured	CON.	(baseline)				
		Non-injured	PPM.	**Pre-surgery**	vs.			
		Non-injured	CON.	(baseline)				
	Extensors	Injured	PPM.	**Pre-surgery**	vs.	**-109.5%**		
		Injured	CON.	(baseline)		**-140.9%**		
		Non-injured	PPM.	**Pre-surgery**	vs.	**269.9%**		
		Non-injured	CON.	(baseline)		**-70.0%**		

TABLE 63 - Percentage change (%) of scores from pre-ACLR surgery (baseline) versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for C-BOMs (PF and RFD). Results presented as either negative or positive change scores from pre-surgery (mean scores) versus each assessment occasions. Highlighted values indicate significant interaction ($p < 0.05$). All C-BOMs were evaluated injured and non-injured limbs associated with the knee flexors and knee extensor musculature separately.

CLIN-BOM.	MUSCULATURE ASSESSED (KNEE FLEXOR or EXTENSORS).	INJURED / NON-INJURED LIMBS.	REHABILITATION GROUP CONDITION.	ASSESSMENT OCCASION: (PRE-SURGERY, 6, 12, AND 24-WEEKS POST-SURGERY).				
PF	Flexors	Injured	PPM.	**Pre-surgery** (baseline)	vs.	**-23.9%**	**-13.8%**	**2.1%**
		Injured	CON.			**-19.2%**	**-10.8%**	**-0.5%**
		Non-injured	PPM.	**Pre-surgery** (baseline)	vs.	**6.5%**	**5.9%**	**15.4%**
		Non-injured	CON.			**0.9%**	**0.7%**	**2.9%**
	Extensors	Injured	PPM.	**Pre-surgery** (baseline)	vs.	**-27.7%**		**0.4%**
		Injured	CON.			**-26.9%**		**-1.7%**
		Non-injured	PPM.	**Pre-surgery** (baseline)	vs.	**-8.2%**		**2.3%**
		Non-injured	CON.			**-12.9%**		**-2.7%**
RFD	Flexors	Injured	PPM.	**Pre-surgery** (baseline)	vs.			
		Injured	CON.					
		Non-injured	PPM.	**Pre-surgery** (baseline)	vs.			
		Non-injured	CON.					
	Extensors	Injured	PPM.	**Pre-surgery** (baseline)	vs.			**-6.1%**
		Injured	CON.					**-3.6%**
		Non-injured	PPM.	**Pre-surgery** (baseline)	vs.			**-12.0%**
		Non-injured	CON.					**-3.4%**

TABLE 64 - Percentage change (%) of scores from pre-ACLR surgery (baseline) versus 6, 12, and 24 weeks post-ACLR surgery for PPM and CON rehabilitation groups for C-BOMs (EMD). Results presented as either negative or positive change scores from pre-surgery (mean scores) versus each assessment occasions. Highlighted values indicate significant interaction (p< 0.05). All C-BOMs were evaluated injured and non-injured limbs associated with the knee flexors and knee extensor musculature separately.

CLIN-BOM.	**MUSCULATURE ASSESSED** (KNEE FLEXOR or EXTENSORS).	**INJURED / NON-INJURED LIMBS.**	**REHABILITATION GROUP CONDITION.**	**ASSESSMENT OCCASION:** (PRE-SURGERY, 6, 12, AND 24-WEEKS POST-SURGERY).				
EMD	Flexors	Injured	PPM.	**Pre-surgery**	vs.	**-19.0%**	**-5.0%**	**0.3%**
		Injured	CON.	(baseline)		**-12.1%**	**8.6%**	**-0.1%**
		Non-injured	PPM.	**Pre-surgery**	vs.	**-8.6%**	**7.4%**	**1.9%**
		Non-injured	CON.	(baseline)		**-3.2%**	**6.2%**	**1.8%**
	Extensors	Injured	PPM.	**Pre-surgery**	vs.	**-5.5%**		**-0.6%**
		Injured	CON.	(baseline)		**-3.9%**		**1.2%**
		Non-injured	PPM.	**Pre-surgery**	vs.	**1.1%**		**2.6%**
		Non-injured	CON.	(baseline)		**2.2%**		**2.8%**

7.5.3 - Verification of the duration, volume, modes and intensity of exercise conditioning associated with PPM and CON rehabilitation groups

It was important to quantify each participant's own exercise and rehabilitation both at home and in leisure-based settings, as well as within patients own physiotherapy appointments. All structured supervised hospital-based rehabilitation was calculated (total-time in minutes) by the physiotherapist **(TABLE 65)**. Home-based and leisure-based rehabilitation was evaluated using the 7-Day Physical Activity Recall (7D-PAR) P-BOM. The 7D-PAR was assessed at four points in time (pre-ACLR surgery, 6, 12, and 24 weeks post-ACLR surgery) throughout the experimental period by each participant on discussing any home-based (and leisure-based) physical rehabilitation undertaken by the patient in that previous week, via memory recall. All physical activity (i.e., strength, cardiovascular and flexibility) was recorded by reporting the number of minutes spend performing each strength, cardiovascular and flexibility component together with the intensity (Blair, 1985) **(TABLE 66).**

TABLE 65 - Number of physiotherapy appointments, total-time spent in structured hospital-based physical rehabilitation, total Metabolic Equivalent of Task (METs; for calculation see p. 163) [energy cost of physical activities as a multiple of the resting metabolic rate] within home-based and leisure-based physical rehabilitation for PPM and CON rehabilitation groups.

		PPM	CON
Physiotherapy Appointments		12.8 ± 6.1[144]	15.0 ± 5.5
Structured supervised hospital-based rehabilitation (Total-time [mins]).		389.4 ± 180.3	433.8 ± 163.7
Home-based and leisure-based rehabilitation (Total METs).	Pre-surgery :	195.8 ± 67.7	190.1 ± 83.9
	Week 6 :	158.1 ± 66.0	132.2 ± 41.2
	Week 12 :	215.7 ± 86.5	210.4 ± 60.7
	Week 24 :	292.4 ± 123.5	283.2 ± 145.7

144 The number of physiotherapy appointments were calculated from physiotherapist/hospital records. The number of physiotherapy appointment attended by each participant for PPM and CON rehabilitation groups up to 41 weeks post-ACLR surgery is presented in **TABLE 67.**

TABLE 66 - Home and leisure-based rehabilitation (Mean ± SD) evaluated by 7D-PAR examining number of minutes performed in strength, flexibility, and cardiovascular conditioning/exercises performed per week evaluated at assessment occasions pre-surgery, 6, 12, and 24 weeks (memory recall for previous week) for experimental and control groups.

	Strength (time in minutes)	
	PPM	**CON**
Pre-surgery	32.3 ± 21.5	28.2 ± 16.2
6 weeks	62.8 ± 48.7	45.0 ± 27.1
12 weeks	82.7 ± 61.8	66.2 ± 54.4
24 weeks	43.4 ± 27.9	32.8 ± 24.9

	Flexibility (time in minutes)	
	PPM	**CON**
Pre-surgery	9.9 ± 3.9	7.98 ± 5.9
6 weeks	50.8 ± 18.6	47.78 ± 26.5
12 weeks	33.1 ± 16.1	42.57 ± 23.4
24 weeks	20.3 ± 13.1	18.22 ± 19.6

	Cardiovascular (time in minutes)	
	PPM	**CON**
Pre-surgery	48.9 ± 34.2	55.22 ± 21.2
6 weeks	128.4 ± 43.9	102.83 ± 60.8
12 weeks	86.9 ± 41.5	88.13 ± 37.1
24 weeks	171.8 ± 111.1	103.26 ± 131.8

TABLE 67 - Number of physiotherapy appointments attended per week up to 41 weeks post-ACLR surgery for 46 patients.

	Week	PPM	CON
	1	7	6
	2	18	22
	3	15	12
1 month	**4**	20	19
	5	15	19
	6	16	17
	7	15	17
2 months	**8**	18	17
	9	17	12
	10	10	17
	11	13	14
3 months	**12**	10	11
	13	7	16
	14	11	13
	15	6	15
4 months	**16**	7	10
	17	7	12
	18	6	9
	19	4	11
5 months	**20**	7	7
	21	3	9
	22	5	4
	23	3	8
6 months	**24**	5	6
	25	5	7
	26	3	5
	27	1	4
	28	2	3
	29	2	3
	30	0	2
	31	1	4
	32	0	0
	33	2	3
	34	0	3
	35	0	3
	36	1	0
	37	0	2
	38	1	2
	39	1	2
	40	1	3
	41	1	1
	TOTAL	**266**	**350**

7.6 - Sources of Bias and Intention to Treat Analysis

Out of 146 patients arthroscopically verified with unilateral complete ACL rupture during an 18-month period of recruitment, alongside the number of patients fulfilling inclusion and exclusion criteria, 80 patients consented to participate in this study. Following the randomisation procedure prior to ACLR surgery, patients were randomly-allocated to either an experimental (PPM) or a control (CON) rehabilitation groups. However, the total number of patients who offered to participate in this study (i.e., 80 patients) and completed all assessment occasions (i.e., pre-surgery, and at 6, 12, and 24 weeks post-ACLR surgery) [n = 46] were reduced to 23 patients within each rehabilitation groups.

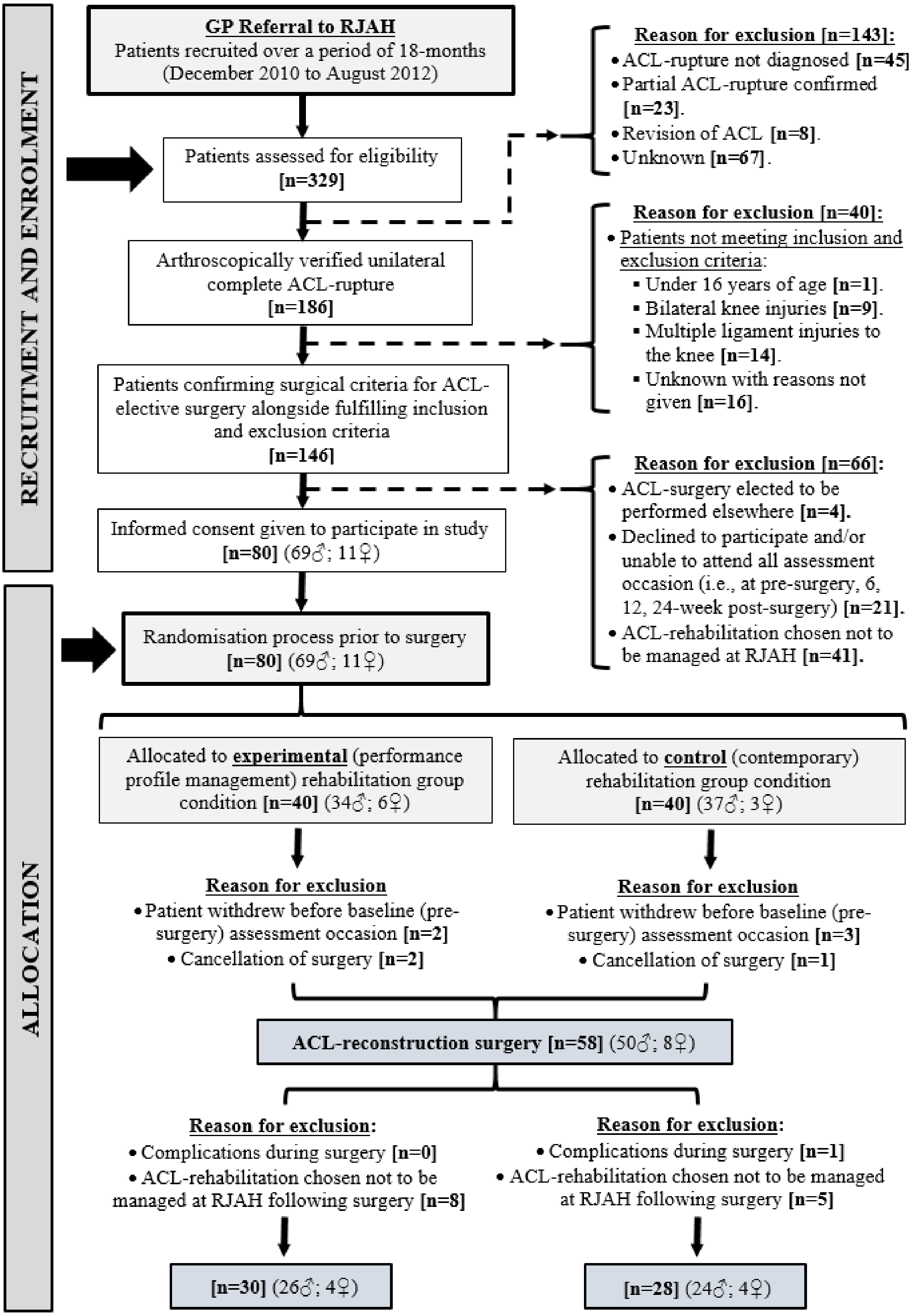
Patients lost to follow-up varied at each assessment occasions. Prior to surgical reconstruction, 22 patients withdrew from the study and did not attend pre-surgery (baseline) assessment occasion dues to cancelation of surgery by request of patient or patients electing not to continue with surgery/post-rehabilitation at RJAH; therefore, these patients were excluded. Thus, 58 patients remained and continued with post-rehabilitative care following ACLR surgery. Twelve patients (20.7%) were lost during follow-up assessment occasions (i.e., 6, 12, and 24-week post-ACLR surgery) with 30 patients within the experiment (PPM) and 28 patients within the control (CON) group condition.

No secondary injuries occurred to any of the patients during the rehabilitation or assessment process. Therefore, secondary injury was not a contributing factor in lost to follow-up. However, as stated in the patient information patients who were lost to follow-up were not questioned as to why they chose to leave the study, although 12 patients did voluntarily offer the reason of work/life commitments intruding on the time available to contribute to the research study contributed for each patient to leaving this study.

The potential influences of bias and compromised external validity on this study's findings associated with altered group composition and altered patterns of outcome data due to patients being lost to follow-up was assessed using separate ANOVAs for each P-BOMs and C-BOMs outcome measure evaluated at pre-surgery (baseline) assessment occasion. These analyses incorporated the factor of group (PPM [n = 23]; CON [n = 23]; Lost to follow-up [n=12]) of the total number of patients remaining in study once completed all phases of rehabilitation and assessment occasions. The lost to follow-up results are presented in **FIGURE 48**.

Comparisons using univariate ANOVA of group mean responses for P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery (baseline) assessment occasion among Lost to follow-up (n = 12), experimental (PPM) (n = 23), and control (CON) (n = 23) rehabilitation group, respectively, were as follow were computed **(APPENDIX 14**; p. 588**)**. In summary, no significant differences were found for P-BOMs and outcomes of C-BOMs associated with the pre-surgery (baseline) testing occasion for the group mean scores among control and experimental group conditions, and those that were lost to follow-up. This suggests that the study data was not biased, despite the withdrawal of 12 patients following the randomisation process.

Post-ACLR surgery, all patients were treated by the same physiotherapist for the duration of their rehabilitation period with partial-blinding to intervention allocation and assessments occasions (conducted at pre-surgery, 6, 12 and 24 weeks post-ACLR surgery). During the experimental period, it had been impossible to fully-blind the physiotherapist and research assessor (author of thesis) to altered characteristics of tissue scarring following ACLR surgery. The busy logistics of care delivery to patients within the NHS, meant that realistically, those individuals involved in the experimental delivery had little additional time to offer attention and the potential for unwanted bias. Double-blinding was not achieved in this study and this may be considered as a limitation. In the presented study, patients were blinded to the treatment and rehabilitation. However, blinding of physiotherapist and assessor was not feasible due to the educational nature of this research and associated budget-limitations. Similarly, individuals involved in data analysis were not blinded to some aspects of the data (testing occasion and group allocations) and this may have contributed to bias in the results.


RECRUITMENT AND ENROLMENT
GP Referral to RJAH
Patients recruited over a period of 18-months (December 2010 to August 2012)
Patients assessed for eligibility [n=329]
Reason for exclusion [n=143]:
• ACL-rupture not diagnosed [n=45]
• Partial ACL-rupture confirmed [n=23].
• Revision of ACL [n=8].
• Unknown [n=67].
Arthroscopically verified unilateral complete ACL-rupture [n=186]
Reason for exclusion [n=40]:
• Patients not meeting inclusion and exclusion criteria:
▪ Under 16 years of age [n=1].
▪ Bilateral knee injuries [n=9].
▪ Multiple ligament injuries to the knee [n=14].
▪ Unknown with reasons not given [n=16].
Patients confirming surgical criteria for ACL-elective surgery alongside fulfilling inclusion and exclusion criteria [n=146]
Reason for exclusion [n=66]:
• ACL-surgery elected to be performed elsewhere [n=4].
• Declined to participate and/or unable to attend all assessment occasion (i.e., at pre-surgery, 6, 12, 24-week post-surgery) [n=21].
• ACL-rehabilitation chosen not to be managed at RJAH [n=41].
Informed consent given to participate in study [n=80] (69♂; 11♀)
ALLOCATION
Randomisation process prior to surgery [n=80] (69♂; 11♀)
Allocated to experimental (performance profile management) rehabilitation group condition [n=40] (34♂; 6♀)
Allocated to control (contemporary) rehabilitation group condition [n=40] (37♂; 3♀)
Reason for exclusion
• Patient withdrew before baseline (pre-surgery) assessment occasion [n=2]
• Cancellation of surgery [n=2]
Reason for exclusion
• Patient withdrew before baseline (pre-surgery) assessment occasion [n=3]
• Cancellation of surgery [n=1]
ACL-reconstruction surgery [n=58] (50♂; 8♀)
Reason for exclusion:
• Complications during surgery [n=0]
• ACL-rehabilitation chosen not to be managed at RJAH following surgery [n=8]
Reason for exclusion:
• Complications during surgery [n=1]
• ACL-rehabilitation chosen not to be managed at RJAH following surgery [n=5]
[n=30] (26♂; 4♀)
[n=28] (24♂; 4♀)

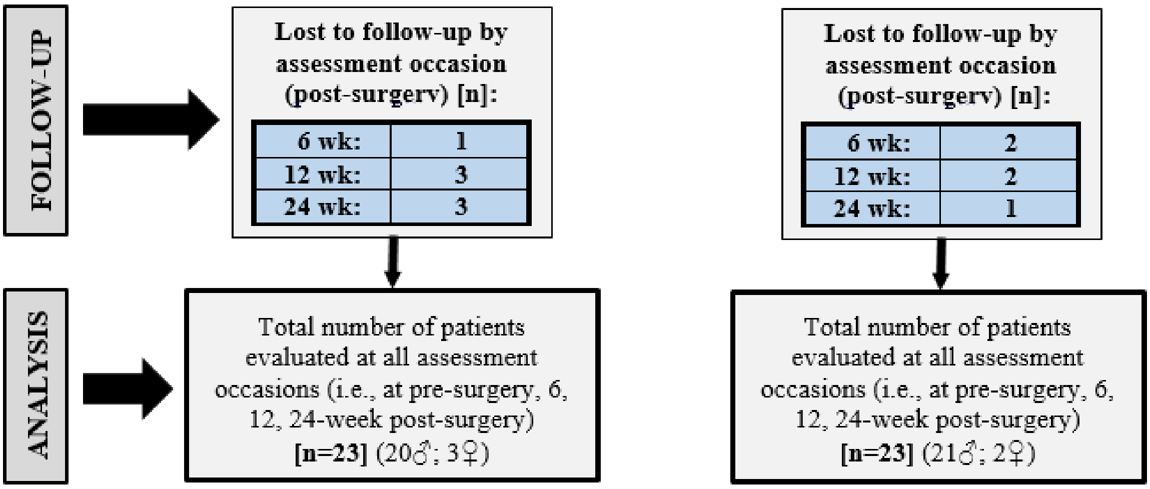


FIGURE 48 - CONSORT diagram summarising of the number of patients recruited, random-allocation, and patient lost to follow-up associated PPM and CON rehabilitation groups.

7.7 - Discussion

The principal objective of this study was to investigate the effects of encouraging patients to self-perceive and manage areas of physical needs within standardised and periodic negotiations with respect to routine physiotherapy appointments following ACLR surgery. An exploratory and feasibility-based study attempted to assess the influence of a relatively simple use of Butler and Hardy's (1992) Performance Profile; a valid client-centred, idiographic assessment and management strategy and outcome measure to understand how an injured patient construes his or her own rehabilitation and recovery following ACL injury. No previous study had investigated use of the Performance Profile on any symptomatic population within orthopaedic patient care that manages post-ACLR surgery rehabilitation using patient-negotiated care pathways.

The Performance Profile assessment provided a visual means for a physiotherapist to evaluate, interpret and monitor over-time in a quantifiable approach to understand a patient's physical self-perceived deficiencies and concerns. Based upon routine evaluation of Performance Profiles, the care delivery pattern and content of the conditioning was modified periodically through patient-physiotherapist negotiation to optimise attainment of the desired improvements. Each participant determined the relative importance of each self-perceived need, as with previous research (Weston et al., 2011b). This had been achieved by asking each patient to rank their profile items/qualities in order of importance and of that required greatest improvement (and priority of treatment) to obtain full recovery. The five areas identified as most important from the patient perspective (as ascertained by patients' importance ratings) were used to initiate discussions between the patient and physiotherapist of how best to achieve the desired improvements from the patient's perspective as these self-perceived were considered most important to the patient. In the latter, this negotiation process was a mean to enhance a more structured patient-centred programme of care.

The comparison of the effects of 24 weeks of novel 'patient-centred' PPM and those produced by contemporary (CON) clinical practice was assessed using factorial analyses-of-variance (ANOVAs). In summary, the evidence endorsed that the null-hypotheses of no difference between the effects of PPM and CON rehabilitation programmes be retained for all P-BOMs (VAS [Pain], IKDC [primary outcome], Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD and SMP-FE [knee flexors]). Thus, across a range of P-BOMs and C-BOMs, the PPM approach to rehabilitation at least matched contemporary practice, and under some circumstances, exceeded its recovery' patterning (Bailey et al., 2015). The preponderance of the retention of null-hypotheses might challenge the notion of whether Type II error rates had been maintained appropriately within the experimental design. A loss-to-follow-up of n = 12 might have inflated experimental 'noise' and have increased the likelihood of Type II error, with commensurate difficulties in correctly detecting subtle differences in performance capabilities. The Intention to Treat analysis suggests these results were not was not biased, despite the withdrawal of 12 patients following the randomisation process **(APPENDIX 14**; p. 588**)**. Nevertheless, at least one comparison properly detected differences between PPM and CON, suggesting that the experimental design sensitivity and power must have been maintained correctly in at least some circumstances. At the very least, these findings endorsed the use of PPM as a viable alternative to current practice.

Notwithstanding the consideration of orthopaedically-relevant covariates outcomes (see Holla et al., 2013) in this study (i.e., BMI, time from injury to ACLR surgery, unstructured physical activity, and the number of routine physiotherapy appointments [visits]), the robust efforts within this study to ensure iso-volumetric comparisons and logistical/financial cost-equivalence in the delivery of PPM and control rehabilitation care pathways, offers further validation for any enhancements to functional or physical outcomes, being properly attributed to a given approach to rehabilitation (in this case, favouring PPM).

It should be noted that the extent of advantage offered by PPM in SMP-FE (knee extensors) was relatively small (a gain of 1.2% compared to CON at 24 weeks post-ACLR surgery, and compared to force errors in asymptomatic joints of 4%, and 20% in ACL-deficient knees) (Gleeson et al, 2008). Sensorimotor Performance (SMP) is the only neuromuscular measure that has been previously and causally linked with ACL injury (Caraffa et al., 1996; Hewett et al., 2006; Griffin et al., 2006). Several prospective RCTs have investigated the potential reasons for ACL injury and evaluated preventative strategies that have predominantly focussed on proprioceptive training. The outcome of some of these studies have suggested that proprioceptive activities may have a major role in injury reduction (Caraffa et al., 1996; Silvers and Mandelbaum, 2007; Ettlinger et al., 1995; Myklebust, Maehlum, Holm, and Bahr, 1998).

One of the well-designed studies (Caraffa et al., 1996), evaluated 600 semi-professional soccer players in two separate groups, and found that following 3 years of 20 minutes (daily) use of wobble wobble-board training of increasing difficulty, reported a reduction in incidence of ACL injuries. An incidence of 1.15 ACL injuries per team per year was found in the control group compared with 0.15 injuries per team per year in the trained athletes. Overall, this study reported 87% decrease in ACL injuries compared with the control group. Similar studies in design however with few participants and length of durations utilising parallel types of interventions have reported matching outcomes (Silvers and Mandelbaum, 2007; Ettlinger et al., 1995; Myklebust et al., 1998). In contrast, some studies have reported no significant differences in incidence of ACL injury in intervention groups in comparison to control groups (Wedderkopp et al., 1999; Soderman et al., 2000). From the limited evidence available, it appears that prolonged progressive proprioceptive training may have the potential to significantly impact dynamic joint protection and ACL injury (Caraffa et al., 1996; Hewett et al., 2006; Griffin et al., 2006).

Testing for Sensorimotor Performance associated with Force Error (FE) initiates an active neuromuscular system as the patient either extends or flexes the knee on an instructor's command, in order to match a blind target force (50% of his/her pre-operative PF). For the purpose of this study, SMP-FE outcome uses a combination of clinician-derived measurements (error of force away from target force in Newton's [N]), and a subjective component of patient-perception of capability to the same target force. More importantly, SMP-FE is the only outcome measure that incorporates the patients' and clinicians' perspective together in one outcome assessment. However, the significance of SMP-FE has come under scrutiny recently, with some researchers suggesting that it isn't as clinically relevant as previously speculated in the literature (Gokeler et al., 2012). Previous research that has led to this conclusion measured either passive Joint Motion Detection or Joint Position Sense (C-BOMs) (Gokeler et al., 2012) and not active force replications, as in this study. As previously found in this study **(Study 4)**, a three-way ANOVA was found to be significant for the knee flexors only associated with SMP-FE.

This suggested that although statistical gains had been noted, the clinical relevance of the advantage may be limited (Davidson and Keating, 2014). However, given that the intervention potency for the PPM of rehabilitation had not been 'optimised' within this study, with PPM essentially being used as a conduit for the initiation of relevant discussion amongst patient, physiotherapist and clinician (rather than a formal method for establishing the intensity of conditioning), the observed effects for PPM may have been muted compared to what might be have been achieved. Future research would be required to examine the deployment of Performance Profiles within clinical practice to ascertain the techniques clinical utility, and more specifically, accounting for the time spent for the negotiation process between patient-physiotherapist for two intervention arms (not directly addressed).

Despite its RCT-nature and characteristics, this study had essentially been a 'pilot' investigating 'real-world' clinical efficacy for PPM. That is, it had fallen between being a study investigating the clinical efficacy of PPM (involving optimised clinical conditions to elicit maximum effects in outcome measures), and that of being a study of clinical effectiveness, involving commensurate delivery of the intervention within the 'real-world' environment associated with the NHS, and perhaps involving multiple centres of care-delivery.

Nevertheless, this study had provided the first attempt to evaluate the efficacy and clinical utility of the PPM within the confines of a relatively controlled setting. A standardisation of ACLR surgical procedures and well-prescribed ACL protocols has potentially provided a suitable clinical environment to empirically examine the PPM approach in comparison with contemporary (CON) clinical practice (Doyle et al., 1998). Moreover, due to the patient sample (see below) and high number of ACLR surgeries perform within the time-frame of the study, stringent inclusion and exclusion were adopted (i.e., patients were excluded if concomitant injuries to the injured knee were present at time of surgery, or having previous knee injury or surgeries to the non-juried limbs etc.) to offer additional robustness to the experimental design whilst offsetting the associated clinical and statistical heterogeneity in the observed treatment effects that were beyond what would be expected by random error (West et al., 2010).

Practically, the experimental design of Study 4, meant that patients had the opportunity to revise Performance Profiles by adding more pressing concerns at the time its administration at each routine visit. Within this process, the adding of additional qualities would assist the physiotherapist to understand any new and relevant concerns from the patient’s perspective that had transpired. Anecdotally, the physiotherapist deploying the Performance Profile found that using the profiling technique within the first consultation appointment was particularly useful in assisting patients to become more self-aware of their injury, and provides patients a useful mechanism for noting all their concerns for later discussions.

For the first time, PPM appears to have offered an approach to musculoskeletal rehabilitation following surgery that matches the effectiveness of current clinician-led delivery, and which most importantly, uses an approach that systematically focuses on individualised care. As such, the physiotherapist or clinician has a viable choice in the delivery of rehabilitation. Future research would be expected to refine and evaluate how best to use the mechanisms of PPM delivery to offer a titration of the intensity of exercise conditioning and facets of rehabilitation to optimise care for each individual patient. In this study, each patient’s Performance Profile was individualised with different items identified by themselves, however in future research it may be more practical to use a ready-prepared fixed profile with predetermined qualities/items, as in previous profiling literature (D'Urso et al., 2002, Butler, 1997) allowing all patients to complete the same items (for injured and non-injured limbs). Future research should therefore evaluate which items (constructs) would be suitable for use in a generic fixed profile appropriate to an ACL-deficient population. Furthermore, in the context of this RCT, the physiotherapist was an integral partner in the construction and discussion of patients' profiles, therefore future research would need to specifically evaluate physiotherapist's perceptions of the technique's usefulness.

Investigating the use of the PPM approach at a single-centred rehabilitation centre and utilising only one physiotherapist would limit the external validity of the thesis' findings. Future investigations would need to consider the delivery of the Performance Profile within a multi-centre environment to confirm the wider applicability of this study's exploratory findings, with multiple physiotherapists adopting the technique and associated procedures. In the latter, the physiotherapist involved the within this study was considerably experienced in the rehabilitation of the knee joint, with 14-years' experience of ACL injury and rehabilitation. It would be equally important to examine the personality traits, communication styles and physiotherapists' approaches to care-delivery, level of experience, and the physiotherapy approaches (i.e., protocol-based approach, clean slate approach, and systematically reassessing a patient's progress and management plan is modified accordingly) (see Tuttle, 2009). As all the aforementioned aspects could potentially be important contributors to the patient-physiotherapist relationship and underpin Patient-Centred Care (Faller, 2003).

Considerable attempts were made to ensure iso-volumetric rehabilitation dosage amongst the two main arms (PPM; CON). To add further complications, participants were not confined to a mandatory number of physiotherapy appointments to attend post-ACLR surgery. Instead, each participant attended routinely allocated physiotherapy appointments under the clinical guidance of the physiotherapist and the relevant hospital policies. Therefore, it was necessary to evaluate and monitor overall duration, volume, modes and intensity of exercise conditioning undertaken by patients, as this was not standardised, but instead, offered as guidance and regulated by clinical need. In the latter, the use of clinical notes and hospital records, patient diaries, and evaluation of the 7D-PAR, were used to record patient's attendance to physiotherapy appointments, and to record the amount of structured hospital-based rehabilitation and home-based and leisure-based rehabilitation performed within two intervention arms. Inter-patient and inter-group differences in the dosage of rehabilitation might affect the responses within the study and hinder the correct attribution of effect by the PPM intervention. As this aspect couldn't be controlled logistically within the experimental design, it was controlled statistically, as necessary.

Importantly, this study incorporated the use of the contralateral limb as an additional control condition (Clark, 2001; Hopper et al., 2002; Reid et al., 2007; Thomeé et al., 2011).

Although some physiological de-conditioning of this control leg's capabilities was likely to have occurred, due to altered physiological loading in the period between ACL injury and ACLR, it nevertheless represented a best estimate of a reference (baseline) performance capability (Gleeson et al., 2008; Bailey et al., 2015). Unexpectedly, a two-factor ANOVA (leg [injured/non-injured] by assessment occasion [pre-surgery, 6, 12, and 24 weeks post-ACLR surgery]) reported a non-significant interaction [$F_{(2,88)} = 0.1$; *ns*]. This was suggesting perhaps (given a priori expectations of greater gains in the injured leg over time), that the performance of the 'control leg' (non-injured limb) was improving at the same rate as that of the injured leg. The bilateral improvement identified can potentially be attributed to the fact that the holistic (bi-lateral) nature of the ACL rehabilitation performed (Briggs et al., 2009).

Further, following significant ACL injury/rupture, patients will have a reduced functional capacity towards their normal daily activities of living, and refrain from sporting activity due to a number of reasons (Ardern et al., 2013). Initially this might be due to pain and swelling, followed by knee instability and/or fear of re-injury (Hopkins et al., 2000; Ardern et al., 2012a). Therefore, the post-operative period of rehabilitation is likely to show bilateral improvements and illustrates a two-legged rehabilitation programme is required. Similarly, PF, RFD, and EMD (C-BOMs), additionally suggest this observation. To further support, the time from injury to ACLR surgery for PPM and CON rehabilitation groups (164.9 ± 87.4 versus 153.3 ± 118.9 days, respectively) may have resulted in much greater deconditioning of the non-injured limb (Gleeson et al., 2008). The further comparisons of the non-injured (control) leg will be discussed further within the main discussion chapter **(**see **Chapter 8)**, what might be implied clinically by this studies' findings.

The duration of the study design allowed for commonly-deployed P-BOMs and C-BOMs to be recorded prior to the surgery in order to establish a baseline measures, and continued throughout the 6-month period of formal rehabilitation. The participants who had consented to this study had sustained an ACL ligament rupture requiring reconstructive surgery. This population is worthy of investigation, due to the epidemiology of ACL injury and the extensive subsequent rehabilitation from surgery requiring 6 to 9-month rehabilitation (Kvist, 2004; Beynnon et al., 2005; Grinsven et al., 2009; Trees et al., 2009; Van-Grinsven et al., 2010; Lobb et al., 2012; Manske, 2012). The prevalence of ACLR surgery and the longevity of the ensuing rehabilitation suggest a significant cost to the NHS and the process of optimising rehabilitation following ACL injury, within patient-centred approaches would be warranted (Zelle at al., 2005; Paxton at al., 2010). However, patients are offered a standardised rehabilitation programme with only limited adaptation of the service to the needs of each individual patient. Therefore, the rationale for study was developed from a body of evidence in support, although limited, for the assertion that patient-centred approaches should be individually-tailored and based on individual self-perceived needs, as such this integration of patients' needs will have greater efficacy on rehabilitation than standard approaches (Suhonen et al., 2007; Kromer et al., 2010; Hanekom et al., 2012).

As corroborated by the presented Systematic Review **(Study 1: Chapter 3)** and correlational investigation **(Study 2: Chapter 5)**, both suggested that each P-BOMs and C-BOMs potentially reflected important but separate aspect of clinical responses, that are not causally linked. Therefore, for the purpose of the presented study, a battery of outcome measures was required to comprehensively evaluate patient outcomes from both the perspective of the patient and physiotherapist. Notwithstanding, for P-BOMs and C-BOMs, all reporting of non-significant ANOVA's interactions by respective ANOVA's (excluding SMP-FE already discussed), and given that no influence of rehabilitation groups was found, data from PPM and CON rehabilitation groups were pooled and allowed comparison over time, irrespective of rehabilitation group condition performances. Therefore, without group differentiation allowing comparison of patterning of P-BOM and C-BOM outcomes over time for the PPM and CON rehabilitation groups, the secondary question of congruency among P-BOMs and C-BOMs over time, irrespective of rehabilitation groups was investigated.

It would appear that all P-BOMs demonstrated an interaction effect ($p< 0.05$) at the intermediate and late phases of rehabilitation **(**see **TABLE** 61; p. 342**)**. The Lysholm, KOOS (Symptoms) score, and the Performance Profile were the only P-BOMs to be responsive within the acute, intermediate and late phases of rehabilitation. Whereas, the remaining C-BOMs: Single-Leg Hop for distance, ATFD, SMP-FE, PF, EMD, and RFD were found to be sporadically interacted throughout all the phases of rehabilitation. In the latter, only PF and EMD evaluated by the knee flexors associated with the injured and non-injured limbs were found to demonstrate a statistical interaction at all three phases of rehabilitation. Moreover, in light of this outcome, it can be further speculated that with P-BOM and C-BOM outcomes responsive at the varying rehabilitation phases, that a battery of outcome measures must be incorporated throughout ACL rehabilitation (Lavoie et al., 2001; Valier and Kenneth, 2015).

An interesting point to consider was the deployment of the Sensorimotor Performance (in this study), and the discrepancy in the actual objective force errors versus the patient-perceptions in force errors, whereby, the physical component of replicating the force (target force at 50% PF pre-surgery level), in general for both the PPM and CON rehabilitation groups, were 'under-shooting' to a trained target force (i.e., 50% of PF). While conversely, the patient perceptions of replication of a target force was perceived, and in general most cases of patients perceived to be over estimating their capability of force generation. An important clinical consideration may be where a disassociation among P-BOMs and C-BOMs could be hypothesised to incite sub-optimal conditioning within rehabilitation therapy (Terwee et al., 2011). As SMP-FE, the mismatching of patient perception of capabilities to the objectively-derived measurements may potentially increase the risk of further injury, if the patient chooses to undertake activities that he/she was not properly prepared for.

7.8 -Conclusion

This study comprises a novel investigation, evaluating patient-centred musculoskeletal rehabilitation versus current practice. A client-centred Performance Profiling technique (Butler and Hardy, 1992) was adapted accordingly because it allows patient-physiotherapist negotiation and agreement on decisions for subsequent rehabilitation and treatment strategies based on shared decision-making (Gleeson et al., 2008; Yates et al., 2016). A primary clinical question this study investigates was the evaluation of individualisation effects and patient contribution to the design of their own physiotherapeutic care programme (an enhanced, structured patient-centred approach). No previous study had investigated the Performance Profile on any symptomatic population within individual orthopaedic patient care that manages post-surgery rehabilitation using patient-negotiated care pathways.

The Performance Profile was proposed as a suitable medium to initiate patient-centred approaches to patient care (Doyle et al., 1998; Gleeson et al., 2005; Gleeson et al., 2008), and the outcome of this RCT **(Study 4)** provides evidence that the PPM and CON rehabilitation group conditions are efficacious. Both intervention arms (PPM and CON groups) provide improvements in performance capability demonstrating equal parity of patient outcomes, as evaluated by P-BOMs and C-BOMs, post-ACLR surgery and throughout a 24 week-period of rehabilitation. Although, no significant differences in P-BOMs and C-BOMs were found by PPM and CON rehabilitation groups (other than a significant interaction between SMP), the Performance Profile may be a suitable medium to initiate patient-centred approaches, in particular to understand patients' self-perceived needs.

The Performance Profile requires time to be delivered correctly (introduction and elicitation of Performance Profile ranging between 6.32 to 12.52 minutes), and the presented results further support the findings from Study 3 **(Chapter 6: Reliability investigation),** that the Performance Profile is comparable to or quicker than some of the more traditional P-BOMs such as the IKDC, which is reported to take at least 10 minutes to administer and 5 minutes to score (Collins et al., 2011). Noteworthy too is that, following the serial completions of Performance Profiles post-ACLR surgery and throughout 24 weeks of rehabilitation within each routine physiotherapy appointment attended, the time taken to complete Performance Profiles was dramatically reduced with increased practice and familiarity with the technique (data not shown). The delivery of the Performance Profile for this study comprehensively evaluated the injured and non-injured limbs separately, also evaluating the relative importance of each quality within each patient's profile. It was necessary for the deployment of the PPM rehabilitation group, that the five areas identified as most important from the patient's perspective (as ascertained by the patients' importance ratings) would be used to initiate discussions between the patient and physiotherapist concerning how best to achieve the desired improvements from the patient's perspective, as these self-perceived needs were considered most important to the patient. It could be speculated that delivery of PPM could be reduced in terms of patient involvement, considerably reducing the associated administration times if only the injured limb was evaluated.

An additional advantage of the Performance Profile over other P-BOMs is that the Performance Profile can be used as both an assessment outcome and management tool concomitantly. As the Performance Profile's construction and ease of interpretation differs from traditional P-BOMs, such as the IKDC and KOOS. Indeed, the Performance Profile can be interpreted without scoring thanks to the visual representation of patients' needs, therefore its simplistic nature may be more suited to the time constraints of clinical practice and consequently more feasible and less burdensome administratively (or clinician-friendly) for physiotherapists.

On balance, the findings from this study suggest that there is a matching in performance outcomes of the included P-BOMs and C-BOMs over the experimental design of the study, alongside varying degree of responsiveness of outcome measures over a rehabilitation period of 6 months. Clinicians should be cautious not to progress and plan their rehabilitative regime based on a single specific outcome measure, but should continue to deploy a battery of P-BOMs and C-BOMs to holistically evaluate patient outcomes and justify clinical decision-making (Michener, 2011; Lavoie et al., 2001). The PPM approach to rehabilitation at least matched contemporary practice. This study does support the deployment of the Performance Profile to ACL-deficient patients as a means to evaluate patient outcomes over time and provides the first initial evidence to support the introduction of this profiling approach to clinical practice, which can be applied immediately in a clinical setting (and among other symptomatic populations), without extra cost.

CHAPTER EIGHT

Discussion of the Thesis, Summary of Methodological Strengths and Limitations including Recommendations for Future Study

8.1 - General discussion

The purpose of this chapter is to critically evaluate and synthesise the findings from the four clinical research studies (Studies 1 to 4; chapters 3, 4, 6, and 7, respectively), addressing research questions that had underpinned the primary and secondary clinical aims of the thesis (p. 61). This discussion chapter will consider each chapter in terms of its outcome, methodological strengths and limitations, followed by recommendations for future research.

8.1.1. - Primary clinical question

The primary clinical question that this thesis investigated was the novel evaluation of individualisation effects and patient contribution to the design of their self-managed physiotherapeutic care programmes (enhanced, structured patient-centred approach). A client-centred Performance Profile (Butler and Hardy, 1992) had been adapted accordingly because it allows patient-physiotherapist negotiation and agreement on decisions on subsequent rehabilitation-treatment strategies based on shared decision-making (Gleeson et al., 2008; Yates et al., 2016). This research aimed to promote an understanding of patients' needs and verify the circumstances in which rehabilitation might be enhanced by allowing a patient to play a key role in shaping his or her treatment, leading to recovery. The Performance Profile was proposed as a suitable medium to initiate patient-centred approaches to patient care (Doyle et al., 1998; Gleeson et al., 2005; Gleeson et al., 2008).

In preparation for the clinical deployment of the Performance Profile in a prospective, controlled RCT **(Study 4: Chapter 7)**, it was important to further investigate and substantiate aspects of the Performance Profile's psychometric measurement properties **(Study 3: Chapter 6)**. This would facilitate the Performance Profile's proper use as an assessment tool in this thesis and potentially, within wider clinical practice. Clinimetric and psychometric assessment capabilities have not yet been established for the use of the Performance Profile with any symptomatic populations (Doyle et al., 1998; Doyle et al., 1997; Gleeson et al., 2005; Gleeson et al., 2008; Yates et al., 2016). The outcome of this reliability study **(Chapter 6)** will be discussed shortly.

Evaluation of the novel application of the Performance Profile within a clinical setting, in comparison to other commonly-deployed P-BOMs[145] and C-BOMs[146], might permit informed speculation over the number and type of outcome measures that would be necessary to correctly describe progression and properly describe changes in functional and physical capacities, whilst allowing an initial insight into the Performance Profile within this ACL-deficient population.

[145] Patient-Based Outcome Measures (P-BOMs).
[146] Clinician-Based Outcome Measures (C-BOMs).

It had been expected that deploying the Performance Profile as an assessment tool within a rehabilitation setting in which patients' responses would likely involve much larger changes (effects) in performance during recovery from surgery, would better suit the psychometric characteristics of the Performance Profile (Doyle et al., 1996; Doyle et al., 1997; Doyle et al., 1998; Gleeson et al., 2005; Gleeson et al., 2008).

The psychometric characteristics of the protocol for Performance Profile matched or exceeded those of other P-BOMs, and to a large extent, even matched those of frequently-used C-BOMs. Importantly, this thesis offered evidence for the psychometric qualities of the Performance Profile that endorsed a more sophisticated use for it in the future, to both successfully offer mechanisms for the precise titration of the intensity of conditioning and by means of facilitating relatively short inter-assessment periods associated with favourable measurement responsiveness, the minimum duration between assessment times across the rehabilitation period. The reproducibility of the Performance Profile, involving a MCD (+/- 0.8 units [95% confidence limits]; maximum is 10 on measurement' scale), suggested that it would correctly discern difference in an individual patient's perceived need across the 6-week assessment occasions (for example, change effect in Performance Profile: 3.7 units, baseline to 6 weeks post-surgery). The 2-week review protocol used within the PPM of rehabilitation in this thesis **(Study 4: Intervention RCT investigation)**, which essentially deployed a verbal discussion between the physiotherapist and patient, of perceived need within the PPM, might still have benefitted clinimetrically from a systematic approach to the titration of need and optimising an individual's dosage of rehabilitation during the negotiation process. This would be an investigative aim for future research, since as noted previously, the PPM in this thesis was a 'pilot' approach that used Performance Profile simply as a tool for discussion between the patient, physiotherapist and clinician.

The return to normal function is the main aim of any rehabilitation programme. The assessment of the Single-Leg Hop for distance is an objective (C-BOM) assessing function that is often used following ACLR surgery to assess whether a patient can safely return to sport (Reid et al., 2007). As the hop performance outcome is commonly deployed in clinical practice, and based on the amount of space available for assessments and the reliability of this measure, it was deemed most appropriate in comparison to shuttle sprint or carioca, for example (Clarke 2001; Gustavsson et al., 2006). In addition to this, and contrary to contemporary clinical practice, this thesis evaluated the use of dynamometry (i.e., muscle strength and neuromuscular index outcomes), arthrometry (i.e., ATFD; knee laxity) and proprioceptive testing equipment (SMP) to potentially understand the neuro-musculoskeletal and sensorimotor performance capabilities of patients during recovery and rehabilitation following ACLR surgery (Gleeson et al., 1996, Gleeson et al., 2002; Minshull et al., 2007; Bailey et al., 2015).

The comparison of the effects of 24 weeks of novel 'patient-centred' PPM rehabilitative intervention and those produced by contemporary (CON) clinical practice was assessed using factorial analyses-of-variance (ANOVAs). The evidence from P-BOMs and C-BOMs showed no difference between the effects of PPM and CON rehabilitation programmes **(**see **SUMMARY**: **TABLE** for the thesis' primary clinical question**)**. However, it was interesting to note that for one important outcome measure, SMP-FE, prominent previously because of its causal linkage to ACL injury (Hewett et al., 2006), rehabilitation using PPM elicited slighty superior Sensorimotor Performance to that produced by contemporary practice.

Overall, as assessed by a range of P-BOMs and C-BOMs, the PPM approach to rehabilitation at least matched contemporary practice, and under some circumstances, exceeded its recovery patterning. Evidence from Study 2 **(Chapter 5: Correlation investigation)** found that of the correlation coefficients that were both statistically ($p< 0.05$) and clinically relevant ($r \leq 0.70$), only a small number of relationships were found between P-BOMs and C-BOM. Several of these correlations were between the IKDC ($r = -0.70$, $p< 0.001$) and Performance Profile versus SMP-FE ($r = 0.42$ to 0.45; $p< 0.05$). It is reassuring that SMP, alongside the other neuromuscular outcome measures (PF, RFD, EMD), were also found to be statistically significant ($p< 0.05$) and clinically relevant ($r\geq 0.70$). It should be noted that these neuromuscular outcomes (PF, RFD, and EMD) have also all been tentatively linked with dynamic stability of the knee and ACL injury and prevention (Caraffa et al., 1996; Silvers and Mandelbaum, 2007; Ettlinger et al., 1995; Myklebust et al., 1998).

An interesting point to further consider was the deployment of the Sensorimotor Performance, and the discrepancy in the actual objective force errors versus the patient perceptions in force errors, whereby the physical component of replicating the force (target force at 50% PF pre-surgery level) was, in general, for both the PPM and CON rehabilitation groups, 'under-shooting' to a trained target force (i.e., 50% of PF). While conversely, in most cases patients' perceived they were over estimating their capability of force generation. An important clinical consideration may be where a disassociation among P-BOMs and C-BOMs could be hypothesised to incite sub-optimal conditioning within rehabilitation therapy (Terwee et al., 2011). As with SMP-FE, the mismatching of patient perception of capabilities to the objectively-derived measurements may potentially increase the risk of further injury, if the patient chooses to undertake activities that he/she was not properly prepared for.

Moreover, in Yates et al. (2016), it was found that there was in fact a mismatch in patients' perceptions (Performance Profile) versus their actual physical performance (evaluated by C-BOMs: PF, RFD, EMD, and SMP-FE), where a latency of two weeks was found. It was speculated that over this period of time from ACL surgery to 10 weeks' post-rehabilitation, participants had achieved limited experience of stressing or testing the capability of the injured knee joint, and had become habituated to the 'feel' of the injured leg. This type of compensatory effect may have led to a patient-perceived scaling of response that under-estimated the extent of inter-limb discrepancy of C-BOM capabilities prior to ACL injury and ACLR surgery. Clinicians should be aware that participants are likely to considerably miscalibrate their true capabilities and perceive high levels of dysfunction over this initial period of (acute) rehabilitation.

Testing for Sensorimotor Performance associated with Force Error (FE) initiates an active neuromuscular system as the patient either extends or flexes the knee on an instructor's command, in order to match a blind target force (50% of his/her pre-operative PF). For the purpose of this study, SMP-FE outcome uses a combination of clinician-derived measurements (error of force away from target force in Newton's [N]), and a subjective component of patient perception of capability to the same target force. More importantly, SMP-FE is the only outcome measure that incorporates the patients' and clinicians' perspective together in one outcome assessment. However, the significance of SMP-FE has come under scrutiny recently, with some researchers suggesting that it is not as clinically relevant as previously speculated in the literature (Gokeler et al., 2012). Previous research that has led to this conclusion measured either passive Joint Motion Detection or Joint Position Sense (C-BOMs) (Gokeler et al., 2012) and not active force replications, as in this study. There is currently no standard test for knee joint proprioception and sensorimotor control (Roberts et al., 2000; Roberts et al., 2007), therefore, future research would be required to evaluate other methods to determine the relevant role of the sensorimotor system and potential relationships to P-BOMs (Gokeler at al., 2012).

The retention of a preponderance of null hypotheses raises the question of whether type II error rates had been maintained appropriately within the experimental design. A loss-to-follow-up of n = 12 might have inflated experimental 'noise' relatively, and have increased the likelihood of Type II error, with commensurate difficulties in correctly detecting subtle differences in performance capabilities. The Intention to Treat analysis (p. 352) suggested that Study 4's **(Chapter 7: Intervention RCT study)** data was not biased, despite the withdrawal of twelve patients following the randomisation process. Nevertheless, at least one comparison properly detected differences between PPM and CON (a gain of 1.2% compared to CON at 24 weeks post-surgery), suggesting that the experimental design sensitivity and power must have been maintained correctly in at least some circumstances **(APPENDIX 14**; p. 588**)**. In general, the equivalence of outcome between PPM and control suggested reasonably that these findings endorsed the use of PPM as a viable alternative to current practice.

The robust efforts within this study to ensure iso-volumetric comparisons and logistical/financial cost-equivalence in the delivery of PPM and control rehabilitation care pathways, offers further validation for any enhancements to functional or physical outcomes, being properly attributed to a given approach to rehabilitation (in this case, hinting at favouring PPM). The latter does not take into account further reassurances associated with consideration of orthopaedically-relevant covariate outcomes (see Holla et al., 2013) in this study (i.e., BMI, time from injury to ACLR surgery, unstructured physical activity, and the number of routine physiotherapy appointments [visits]).

It should be noted that the extent of advantage offered by PPM in promoting favourable SMP-FE performance was relatively small (a gain of 1.2% compared to CON at 24 weeks post-surgery, and especially when compared to force errors in asymptomatic joints of 4%, and 20% in ACL-deficient knees) (Gleeson et al., 2008). This suggested that although statistical gains had been noted, the clinical relevance of the advantage may be limited. For the first time, PPM appears to have offered an approach to musculoskeletal rehabilitation following surgery that matches the effectiveness of current clinician-led delivery, and which most importantly, uses an approach that systematically focuses on individualised care. As such, the physiotherapist or clinician has a viable choice in the delivery of rehabilitation.

TABLE 68 - Summary (previous page) of the key findings associated with the thesis' primary clinical question, to assess the effects of ACLR and 24 weeks of PPM rehabilitation compared to contemporary CON rehabilitation in patients with ACL deficiency.

PRIMARY QUESTION	KEY FINDINGS FROM STUDY 4 (RCT)
Is there evidence that 24 weeks of post-surgical rehabilitation using PPM improves patient P-BOMs and C-BOMs to a greater extent compared to contemporary (CON) practice?	• RCT **(Study 4: Chapter 7)** provides evidence that both the CON and PPM are efficacious. • Patients following either PPM and CON rehabilitation programmes improved performance (i.e., Single-Leg Hop for distance, ATFD, IKDC, KOOS, Lysholm, Performance Profile, SMP-FE [knee flexors]), PF, EMD, and RFD) to a similar extent over time (24 weeks). • PPM elicited superior (1.2%) SMP-FE (knee extensors) performance compared contemporary practice clinical effectiveness ($F_{(2.5,113.7)GG}$= 3.2, $p <0.05$), a prominent finding because of sensorimotor performance's causal linkage to ACL injury. • Delivery of PPM and CON rehabilitation had been iso-volumetric (by prescription), with expected logistical- and cost-equivalence[147]. • Novel PPM rehabilitation intervention was well-tolerated by patients[148]. • Outcomes of Single-Leg Hop for distance, RFD and EMD: the non-injured (control) leg improved at the same rate as injured leg over time; acknowledging the contribution of bi-lateral/two-legged programmes of post-surgery rehabilitation and conditioning that inevitably affect both injured and non-injured limbs. • The Lysholm, KOOS (Symptoms), and Performance Profile demonstrated greatest interaction effects (group x time) over all rehabilitation phases (and thus, great measurement responsiveness), whereas significant changes in VAS (Pain), IKDC, Lysholm, and KOOS (Pain, Function, Sport/rec, QoL) occurred only between 12 weeks and 24 weeks. • ATFD, PF [flexors], and EMD [flexors]) demonstrated the greatest interactions (group x time) and measurement responsiveness at all rehabilitation phases, with the remaining C-BOMs offering occasional interactions. • This study supports the deployment of the Performance Profile with patients suffering ACL deficiency and undergoing corrective surgery with rehabilitation, as a means to evaluate individualised patients' perceptions of functional capability. Results provide initial support for the introduction of the Performance Profile to clinical practice, with minimal additional logistical costs. . The Performance Profile (time for introduction and delivery: 6:32 to 12:52 minutes over a six-month period [including time for re-administration of 1:50 to 6:23 minutes]) offers a viable assessment (and rehabilitation management) tool that may be much quicker and cost-effective to deliver than traditional P-BOMs (for example, IKDC needs a total of 15 minutes to administer/score over the equivalent period).

147 The practical utilty of the Performance Profile has been evaluated in Chapter 6 (Study 3) and preliminary evidence suggests that this profiling approach is comparable to other P-BOMs, and would be cost-effective to deploy and non-problematic logistically. Future research would be required to evaluate this further.

148 The physiotherapist routinely deploying the Performance Profile found (anadotecally) that the profiling approach was well tolerated by patients. As reported in **Chapter 6 (Study 3)** the Performance Profile was administered in a short period of time without any adverse concerns, suggesting that the Performance Profile was well tolerated. Future research would be required to evaluate this further.

8.1.2. - Secondary clinical question - Correlational evidence

One of the recurring themes emerging from the findings of the thesis, driven in part by expectations from the systematic literature review **(Study 1)**, and then by the findings from Study 2 **(Chapter 5: Correlation investigation)** has been the relationships between P-BOMs and C-BOMs. The proxy use of a P-BOM to replace time- and cost-intensive C-BOMs offers logistical advantages during the description and monitoring of functional and performance capabilities. In contrast to the findings of the literature review in which the evidence for compromised relationships amongst P-BOMs and C-BOMs had been accrued across many separate studies, the thesis offers evidence from a selection of outcome measures (P-BOMs and C-BOMs) that reflected those frequently used in clinical practice and those offering novelty (Performance Profile), but importantly, measured simultaneously within a single clinical population. Thus, the consistent lack of statistically and clinically-relevant correlation amongst P-BOMs, amongst C-BOMs, and between P-BOMs and C-BOMs shown in Study 2 **(Chapter 5: Correlation investigation)** (see **SUMMARY: TABLE 68)** for the thesis' secondary clinical question**)** further endorses the quandaries that challenge clinicians and researchers. These centre on determining the minimum number of either P-BOMs or C-BOMs that might be needed to properly describe changes in functional or physical performance of patients during their rehabilitation, and importantly, the dilemma of whether P-BOMs or C-BOMs offer most validity (see Reiman and Manske, 2011). With some confidence - being very speculative and conservative in the interpretation of results - the outcome of the systematic review (Study 1)[149] and Study 2 **(Chapter 5: Correlation investigation)** have confirmed that P-BOMs (IKDC, VAS [Pain], and KOOS [QoL]) and C-BOMs (PF, EMD and SMP-FE) demonstrate the highest form of potential clinical utility ($r \geq = 0.90$), albeit with only a small number of P-BOMs and C-BOMs fulfilling this criterion.

Nevertheless, the compromised correlations between P-BOMs and C-BOMs ($r< 0.4$, Study 2: Chapter 5) are congruous with the literature (Clarke, 2001; Pua et al., 2008) and suggest that patients are not capable of correctly calibrating their perceptions of capability against objectively-measured performance (Fitzgerald et al., 2001). This interpretation is further corroborated by findings from Study 2 **(Chapter 5: Correlation investigation)** and Study 4 (**Chapter 7: Intervention RCT investigation,** comparisons, respectively, in which directly comparable patient-perceived and objectively-measured capability for the outcome of Sensorimotor Performance (SMP-FE) also showed low correlation ($r< 0.3$; $p< 0.05$) (Gokeler et al., 2011).

[149] The following P-BOMs (Cincinnati, Lysholm, Noyes (modified), VAS, FAS, Bi-POMs, ERAIQ, and Performance profile) and C-BOMs (Hop [6m-timed], Stairs Hopple (timed), ATFD, PF, PT, TW, and EMD) were found to have most clinical relevance ($r = 0.80$ to 0.90) from Study 1 **(Chapter 3: Systematic review)**.

The compromised correlations amongst P-BOMs and amongst C-BOMs **(**r< 0.3, Study 2: Chapter 5) have not systematically been reported previously within the literature (Clarke, 2001; Fitzgerald et al., 2001; Pua et al., 2008). Low correlation suggests that each outcome is assessing a different component of capability (that does not share variance with other relevant outcomes) and that, given the absence of a gold standard outcome to define a hierarchy of validity (Valier et al., 2015), information from all outcomes might be important and needed to capture a complete profile of functional or performance capabilities of individual patients. In the latter scenario, the limitations to the minimum clinical difference that might be properly detected with appropriate statistical confidence will depend on, and be limited by, the psychometric characteristics of the outcome measure with the poorest precision or sensitivity.

TABLE 69 - Summary (previous page) of key findings associated with the thesis' secondary clinical aim of exploring relationships amongst P-BOMs and C-BOMs used to assess performance following ACL rehabilitation at pre-surgery and at 24 weeks of rehabilitation in patients with ACL deficiency.

SECONDARY QUESTION:	**KEY FINDINGS FROM STUDY 2:**
Are there relationships amongst P-BOMs and C-BOMs at pre-surgery, and throughout 24 weeks of ACL rehabilitation prior to, and following ACLR surgery?	• Overall, there was a lack of statistically (317/2808 **[11%]**) and clinically-relevant correlations (39/2808 **[1.4%]**), amongst P-BOMs, amongst C-BOMs, and between P-BOMs and C-BOMs (corroborated by the systematic review's findings). • Performance Profile appeared infrequently/sporadically among all three aspects of inter-correlation analyses at pre-surgery/rehabilitation. • The proxy use of a P-BOM (including Performance) to replace time- and cost-intensive C-BOMs was not supported. • Each P-BOM/C-BOM might be contributing to the assessment of a separate, but potentially important aspect of function and recovery. • Thus, clinical practice/research should continue to deploy a battery of P-BOMs/C-BOMs to holistically evaluate patients' functional and physical capabilities. • Physiotherapists should avoid promoting a patient rehabilitative regime using evaluations of progression and improvement based on a single outcome measure. • The minimum number of P-BOMs and/or C-BOMs required to properly describe changes in functional or physical performance within a multivariate format, is not yet known. • It is unclear whether P-BOMs or C-BOMs offer most validity clinically.

Currently, the relative importance of outcome measures (P-BOMs or C-BOMs) that are required to deliver a global assessment and manage patients' post-ACL injury care, remains unknown (Phillips et al., 2000). Understanding the patterns of inter-correlations among P-BOMs, C-BOMs, and amongst P-BOMs and C-BOMs might permit informed speculation over the number of outcome measures that might be necessary within rehabilitation, plus the hierarchy of outcome measures to ensured enhanced functional outcome **(**see **Chapter 5: study 2)**. It was hypothesised that if a robust association among P-BOMs and C-BOMs was found, then this might indicate the correct scaling of patients' own capability perceptions with C-BOMs. The latter would then facilitate the correct proxy use of P-BOMs as efficient substitutes for more complex C-BOMs (if found), which may allow another means to assess patient outcomes. Further, if strong relationships were to have been found amongst the candidate outcome measures, then it could have led to a reduction in the size of the battery of P-BOMs and C-BOMs required in the future to assess patient outcomes following ACLR. The investigation of this secondary question was investigated within Study 1 (**Chapter 3: a systematic review of the literature)** and Study 2 **(Chapter 5: Correlation investigation)**. The outcome of this thesis did not substantiate the single use of one P-BOM and/or C-BOM at pre-surgery, or across the acute, intermediate and late phases of rehabilitation. Also this thesis cannot offer judgement with certainty, on the hierarchy of importance of P-BOMs and C-BOMs that should be deployed within ACL rehabilitation phases.

A meta-analysis was originally proposed alongside this systematic review to evaluate the strength of the relationship between P-BOMs and C-BOMs in patients with ACLD and undergoing ACLR **(**see **Chapter 3**; p. 113**)**. More specifically, the systematic review was conducted to examine the strength of P-BOMs and C-BOMs within ACLD evaluated up to 5 years' post-injury for ACLD, or 5 years' post-ACLR. This systematic review was the first attempt to systematically evaluate P-BOMs and C-BOMs concomitantly with ACL-deficient populations. Ultimately, a narrative synthesis of the findings from all studies was performed due to the heterogeneous nature of their experimental designs and outcome measures (both P-BOMs and C-BOMs). Considering the relatively high number of studies found (30 studies fulfilling the inclusion and exclusion criteria), the heterogeneity of P-BOMs/C-BOMs found were diverse and mostly non-comparable whereby no same P-BOMs was consistently evaluated with the same C-BOMs.

Twenty-six P-BOMs and forty-six C-BOMs were found from the thirty included studies within this review, illustrating the diversity of outcome measures available for assessing study outcomes (Wang et al., 2010; Collins et al., 2011; Almangoush et al., 2014) with very few studies reporting similar outcomes (P-BOMs or C-BOMs). The outcome of the systematic review suggests that overall, while some statistically significant correlations existed among P-BOMs and C-BOMs for ACLD and ACLR patients, most could neither be considered to be sufficiently robust nor to offer clinical relevance to be useful as indices of knee performance. Consequently, the extent and robustness of relationships among P-BOMs and C-BOMs cannot be judged with certainty.

Following an initial scoping search (and discovered following the reviewing process), it was apparent that only a few RCTs actually reported correlational data, therefore, it was more appropriate to evaluate only correlational studies with their primarily/secondary aims to investigate P-BOMs and C-BOMs concomitantly. Thus, only correlational investigations were to be included within the review. It would be more appropriate in future research to examine all types of published research (i.e., including RCTs) to confirm a true representation of correlations between P-BOMs and C-BOMs. Moreover, it may be more relevant to further evaluate several more electronic databases to determine all studies were found and reviewed. Within the systematic reviewing process, all studies were required to be available in the English language as translation into English was not feasible within the time-frame of this review. Considering this, only two studies were found that were not included in the systematic review for this reason. It might be expected, though unlikely, that these two studies may have changed the outcome of this review. Future research would be required to include all published research in any language.

Although the systematic review was confined to ACLD and ACLR patients, the systematic review could have included other knee pathologies to allow a wider understanding of concomitant relationships. Though this may have affected the external validity of the results, the inclusion might have allowed a suitable number of sub-sets to be included within a subsequent meta-analysis, which was not conducted. With all this in mind, future research would be needed to address the same research questions within larger scale research trials, or to examine other knee pathologies to understand the relationships further.

The outcome of this thesis, as reported by the findings from Study 1 **(Systematic review)** and Study 2, evaluating the relationships between P-BOMs and C-BOMs, are corroborated by studies examining these relationships further to other symptomatic populations, in which a similar strength of correlations was found, some of which were statistically significant and few clinically relevant. Firstly, Dayton et al. (2016) evaluated the Hip Disability and Osteoarthritis Outcome Score activities of daily living and pain subscales (HOOS) (P-BOMs) evaluated concomitantly with the Timed Up and Go (TUG), Stair Climbing Test (SCT), and 6-minute walk (6MW distance) at 1 and 6 months post-total hip replacement. The outcome of this study reported that the HOOS Pain sub-scale scores were not correlated with changes in functional performance at either 1 or 6 months post-surgery at any of the assessment occasions. Specifically, there was poor correlation between change in the HOOS subscale (Pain) and change in the TUG ($r = -0.04$, $p = 0.87$), and between change in the HOOS subscale (Pain) and change in the SCT ($r = 0.04$; $p = 0.85$) from pre-surgery to 1 month post-surgery. Similar to the relationship with the HOOS subscale (ADL), there was a moderate, but significant correlation between the HOOS subscale (Pain) and change in the 6MW distance (r= 0.49, p= 0.02) during the same assessment occasions. Further, poor correlations were found between changes in the HOOS subscale (Pain) and changes in the TUG (r= 0.107, p = 0.64), SCT (r = 0.01, p = 0.96), and 6MW distance (r = 0.07, p = 0.77) during 1 to 6 months post-surgery.

Similarly, another study evaluated the KOOS subscales (ADL) and 6MW distance pre-surgery, and at 1, 3, or 6 months post-surgery for TKA. At all assessment occasions none of the computed relationships were found to be significant or clinical irrelevant. The authors concluded the importance of using C-BOMs within this population when evaluating recovery post-TKA, as opposed to relying solely on P-BOM to evaluate performance (Stevens-Lapsley, Schenkman, and Dayton, 2011). Within the same populations for TKA evaluated at 37 months post-surgery, no significant correlation was observed between the KOOS subscale (Pain, QoL, and ADL) and Knee Society Score (KSS) versus ROM (Vascellari, Schiavetti, Rebuzzi and Coletti, 2016). For OA studies, similar outcomes were found, however, some pockets of significant and clinically relevant relationships were found (Sabirli, Paker, and Bugdayci, 2013; Hicks-Little, Peindl, Hubbard-Turner, and Cordova, 2016). Nonetheless, the interpretation of the results above may not be representative of the various patient populations, and would require further investigation (as previously stated). Similar to the systematic review conducted in Study 1, and in line with the literature, some of the P-BOMs and C-BOMs used makes comparison and interpreation of the results difficult since the studies were mostly non-comparable with no same P-BOMs being consistently evaluated with the same C-BOMs. The consistent lack of statistically significant and clinically relevant correlation between P-BOMs and C-BOMs highlights the challenges faced by clinicians and researchers in other populations.

A subsidiary aim of the systematic review **(Study 1: Chapter 3)** was to address whether an association occurred at differing time-points across a patient's rehabilitation programme. Unfortunately, the outcome of this study does not substantiate the single use of one P-BOM and/or clinician-based outcome measure at pre-surgery, or across the acute, intermediate and late phases of rehabilitation, to accurately reflect knee performance with ACLD/ACLR patients. Therefore, the logical progression was to evaluate a range of P-BOMs and C-BOMs within these phases of rehabilitation. Within the next chapter **(Study 2: Correlation investigation)**, prevalence and robustness of correlations amongst outcome measures throughout the ACL rehabilitation period (0-24 weeks post-surgery) meant that few could be considered to be determinants of functional knee performance. There was also insufficient evidence for the proxy use of P-BOMs (including the Performance Profile) as efficient substitutes for clinician-derived outcome measures. As previously discussed, the findings from Study 2 **(Chapter 5: Correlation investigation)** were corroborated by the presented systematic review **(Study 1: Systematic review)** findings, suggesting that each P-BOM and C-BOM potentially reflected important, but separate aspects of clinical responses, that are not causally linked (Akker-Scheek et al., 2008; Reid et al., 2007).

Therefore, the clinical implications would suggest that clinicians should be cautious not to progress and plan their rehabilitative regime based on a sole and particular outcome measure, but continue to deploy a battery of P-BOMs and C-BOMs to holistically evaluate patient outcomes to justify clinical decision-making (Michener, 2011; Lavoie et al., 2001). Further research is still warranted to continue to investigate the relationship between P-BOMs and C-BOMs which might have important implications to clinical practice, governmental health care strategies, and cost savings to the NHS. In light of the presented results, it can be further speculated that with P-BOMs and C-BOMs demonstrating various interaction effects over varying rehabilitation phases **(**see **TABLE 62** [p. 345]; **TABLE 63** [p. 345]; and **TABLE** [p. 346]**)**, a battery of outcomes should be encouraged in clinical practice/research to holistically evaluate patients' functional and physical capabilities.

In summary, although some statistically-significant correlations were found among P-BOMs and C-BOMs, they were not strong enough for clinical relevance, and lacked relevance across rehabilitation phases as determinants of knee functionality and performance. The results of the thesis further corroborate the outcomes of Study 1 **(Chapter 3: Systematic review)**. Therefore, Study 2 **(Chapter 5: Correlation investigation)** suggests and confirms that **(1 :)** with the absence of robust/frequent linkage among P-BOMs and C-BOMs, each outcome might be contributing to a separate, but potentially important aspects of function and recovery, but with no causal linkage; **(2 :)** the proxy use of P-BOMs as efficient substitutes for C-BOMs could not be envisaged based on the results of this study; **(3 :)** the Performance Profile appeared sporadically to correlate with other outcome measures that had been used in this thesis, but overall, it was statistically/clinically irrelevant; **(4 :)** the lack of correlation among P-BOM and C-BOMs could potentially lead to sub-optimal conditioning within rehabilitation therapy, with patient's perceived capabilities being mismatched to the objectively-derived measurements; **(5 :)** the mismatch between patient perceptions and actual function performance capabilities could in fact increase the risk of further injury if the patient chose to undertake activities for which they are unprepared; **(6 :)** clinical practice should continue to deploy numerous P-BOMs/C-BOMs to holistically evaluate patient outcomes; and **(7 :)** physiotherapists should avoid promoting a patient rehabilitative regime based on the development of aspects of performance focusing on a single outcome measure.

8.1.3. - Psychometric characteristics of the Performance Profile

The psychometric characteristics of the Performance Profile including any potential learning and other carry-over effects, have important implications for its proper clinical deployment. A separate one-way analysis-of-variance (ANOVA) with repeated measures revealed no significant differences between five sequential completions of the Performance Profile by patients prior to surgery, for both injured and non-injured limbs. The administration of one Performance Profile appeared to be sufficient for each patient to have accommodated rapidly to the technique. Intra-subject changes in Performance Profile scores were relatively small, and could be attributable to random variability rather than to systematic learning effects.

A subsidiary aim of this study was to assess whether the first five reported self-perceived physical needs identified and rated as being most important by patients, provide greater discrimination of performance and offer more measurement reliability compared to the first 10 items, or 15 items of self-perceived physical needs. The results from ANOVA of group mean coefficient of variability scores across five sequential performance profile completions by patients showed that while the non-injured limb showed relatively low variability despite an increasing number of items included as being important (range CV%: 1.1% to 1.6%), the injured limb showed relatively high coefficients of variation (range CV%: 11.3% to 9.7%), and that the increased variability and thus lowest measurement reproducibility, was most pronounced for the lowest number of items (5 items) ($F_{(2, 80)GG} = 4.65$, $p= 0.019$). The ICC results confirmed similar high single-measurement reliability amongst the three combinations of items for the injured (range: 0.97 to 0.98) and non-injured limbs (0.96 to 0.98). Therefore, it had been deemed reasonable within the thesis, to have adopted 10 items of importance as a pragmatic trade-off between expediency and measurement precision for the description of patients' Performance Profile responses.

Several other clinical implications of this finding need to be considered. Indeed, patients within a rehabilitation programme of care may differ to athletes, as it could be argued that athletes' profile items would be relatively stable and the number of items would remain constant, in contrast to a clinical setting where items (constructs) are heterogeneous (Batterham and George, 2003). Further, the profiling items identified at pre-surgery by patients could potentially be very different to the items that could be elicited at the later stages of rehabilitation. Therefore, it would be appropriate not to reduce patients' profiles to a 5-item version (as in Study 4), and similarly a 10-item version, but allow patients to have a wide array of self-perceived needs, with an option to add other profile items, to assist in patient-physiotherapist negotiation to optimise attainment of the desired improvements.

It is interesting that Butler and Hardy's (1992) traditional Performance Profiling procedure has since become a template from which a variety of alternative procedures have been adapted (Weston, 2005; Weston et al., 2008; Weston et al., 2013), and of which variations in this procedure have been made to suit the clinical nature of the studies within this thesis (Gleeson et al., 2008). Considering the differing variations of the Performance Profile currently deployed (see Weston et al., 2013), it was the purpose of this thesis to use Butler and Hardy's

(1992) profiling procedure without significant alteration of protocols. Nevertheless, a 'revised' and 'extended' version of the Performance Profile procedure has now recently been developed (Gucciardi and Gordon, 2009a) and is designed to attempt to understand all the key tenets of the Personal Construct Psychology approach (Gucciardi and Gordon, 2009b). In contrast, Gucciardi and Gordon (2009b) explained that Butler and Hardy's (1992) Performance Profile only incorporated some elements of the Personal Construct Theory. For example, only four corollaries: individuality, commonality, sociality and organisation, within the conceptual framework were generally examined, with the remaining seven corollaries: construction, choice, modulation, experience, dichotomy, range and fragmentation rarely being assessed.

TABLE 70 - Summary of key findings associated with Study 3.

CHAPTER 6	**KEY FINDINGS FROM STUDY 3: RELIABILITY**
What are the psychometric characteristics (single-measurement reliability, reproducibility and responsiveness to change) of the Performance Profile (pre- versus post-ACLR surgery)?	• Study 3 was the first investigation to evaluate the Performance Profile's reliability characteristics in a symptomatic population following ACL injury and ACLR surgery. • Patients were familiarised and accommodated rapidly to the Performance Profile. Intra-subject changes in Performance Profile scores over days, could be attributed to random variability, rather than to systematic learning effects. • The first five self-perceived needs rated most important provided slightly inferior reproducibility but similar single-measurement reliability compared with the first ten and fifteen self-perceived needs rated as being most important. Measurement errors were five-fold greater for the injured leg compared to the non-injured limb. • Measurement responsiveness from pre- to post-ACLR surgery supports the Performance Profile's capability to detect changes in performance of the injured limb (3.34-unit reduction [57.7% reduction compared to baseline at pre-surgery]). • Performance Profiling demonstrated suitable psychometric measurement reliability and reproducibility. • Introduction and elicitation of Performance Profiles prior to ACLR was well tolerated by patients and administered easily (introduction and elicitation of PP: 6:32 to 12:52 minutes), and was relatively quick to re-administer (1:50 to 6:23 minutes).

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8.1.4. - Clinical Implications

Implications of the 'group-related' findings for individual patients: Patients in the PPM and CON rehabilitation group showed similar patterns of recovery across the 24-week programme of post-ACLR care, across most of the P-BOMs and C-BOMs that has been selected as indicators of functional and physical performance in this thesis. The question of whether these findings would have been meaningful to individual patients cannot be determined by only reporting the statistically significant interaction effects over time. The graphical plotting of each individual patient's response to rehabilitative conditioning (change score, or raw effect from pre-surgery to 24 weeks post-ACLR surgery) against his/her average score over the same period of assessment for P-BOMs such as IKDC and Performance Profiles (the IKDC is the primary outcome measure for the thesis) shows potentially important trends in the measurement quality of collective data that might otherwise be masked by consideration of the group mean data only. Superimposed confidence limits, representing either the outcome measure's ability to accurately detect change in performance over time (MCD: Crawford, Briggs, Rodkey, and Steadman, 2007), or representing the Minimally Important Clinical Difference for the patient (MICD, with typically, MCID>MCD [Katz, Pailand, and Ekman, 2015]), permit an appreciation of the proportion of individual patients' scores that would have exceeded the limitations associated with an outcome measure's quality and thus, would have been audited correctly as having showed recovery in the patients.

This scenario provides an integration of evidence from the thesis' RCT for the P-BOMs of Performance Profile and IKDC **(Study 4: Intervention RCT investigation)** and psychometric evaluation of the Performance Profile **(Study 5: Reliability investigation).** The results, plotted on a scatter diagram **(FIGURE 49**, left panel**)** showed that overall, 100% of patients would have exceeded the MCD criterion for Performance Profile (in the absence of more definitive information about MICD, it might be reasonable to assume MICD = MCD) and would thus have shown improvements that were both statistically and clinically meaningful. By contrast, the results for the IKDC showed that 80% (37 out of 46) of the patients had achieved 'MCID' status across 24 weeks of rehabilitation **(FIGURE 49**, right panel**)**. This indicated that the Performance Profile was a suitable outcome measure for detecting change properly across a period of rehabilitative conditioning, and from this perspective of measurement, had exceeded the capabilities of the IKDC (as well as those of the Lysholm, KOOS and VAS (Pain) [not discussed here]). As such, this study does support the deployment of the Performance Profile to ACL-deficient patients as a means to evaluate individualised perspectives on outcomes over time. It perhaps provides the first initial support for the introduction of the Performance Profile into clinical practice, where it could potentially be applied immediately within symptomatic populations, without extra logistical or financial costs. The deployment of Performance Profile may offer a suitable format to initiate patient-centred approaches, in particular to understand patient's self-perceived needs.

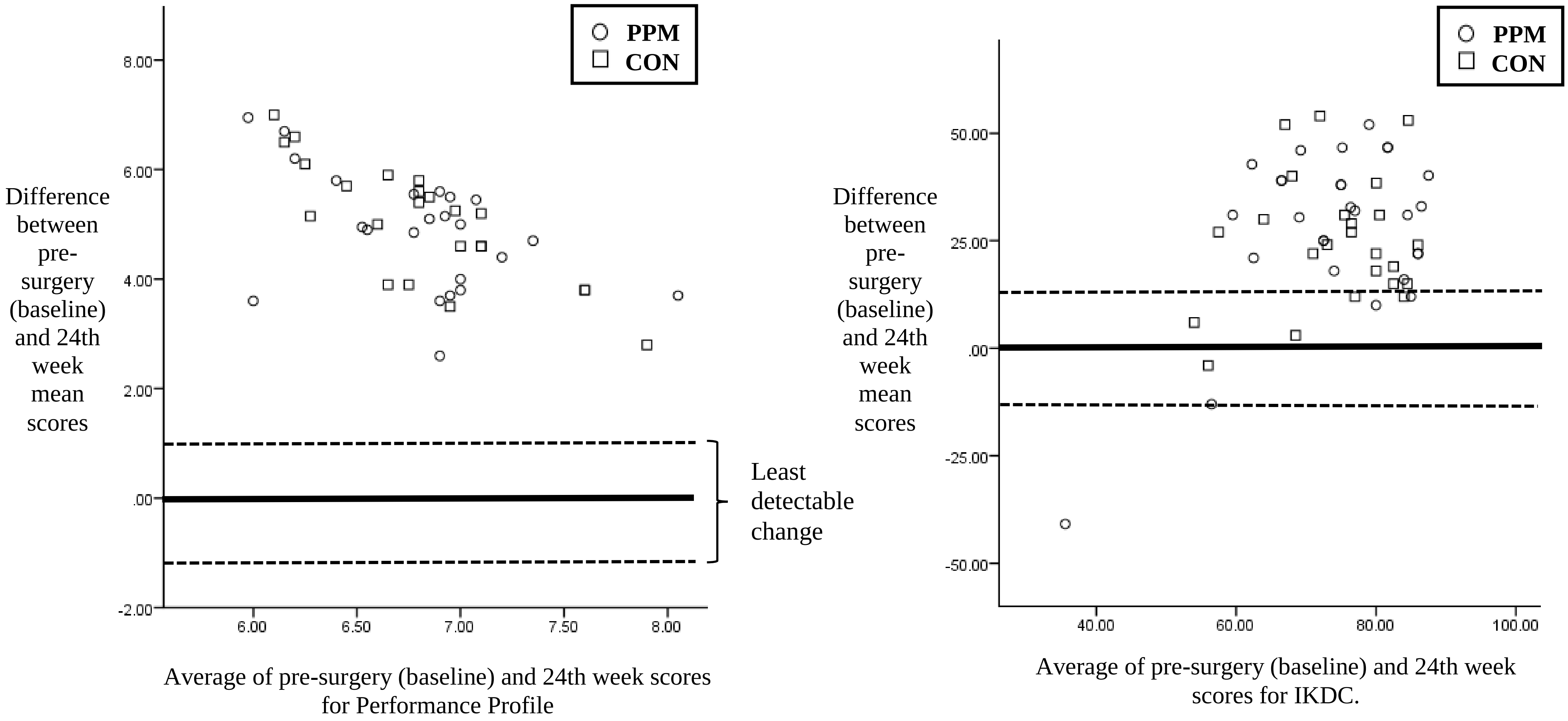

FIGURE 49 - Individual patient's response (change score from pre-surgery [base-line] to 24 weeks post-ACLR surgery) to the 24 weeks of rehabilitative conditioning of P-BOMs (IKDC [primary outcome measure] and Performance Profile) against the patient's average score over the same period of assessment, with superimposed confidence limits indicating least detectable change (dotted line). **<u>NOTE</u>**: MCID for IKDC (not reported in figure) is reported: 11.5-unit change (68% confidence limits) at 12 months (Collins et al., 2011). MCID score is not reported for the Performance Profile and remains unknown.

The outcome of this RCT **(Study 4: Intervention RCT investigation)** provides evidence that the PPM and CON rehabilitation group conditions are efficacious **(**see **TABLE 62** [p. 345]**; TABLE 63** [p. 346]**;** and **TABLE 64** [p. 347]**)**. Both rehabilitative intervention strategies provided statistically significant improvements in performance capability of a similar magnitude demonstrating equal parity of patient outcomes, as evaluated by P-BOMs and C-BOMs. Considerable attempts were made to ensure iso-volumetric rehabilitation dosage amongst the two experimental conditions of Study 4 **(Chapter 7: Intervention RCT investigation** [PPM/CON conditions]**)**. To add further complications, participants were not confined to a mandated number of physiotherapy appointments within their post-surgery rehabilitation. Instead, each participant attended routinely allocated physiotherapy appointments under the clinical guidance of the physiotherapist and in accordance with the relevant hospital policies. It had therefore been necessary to evaluate and monitor the overall duration, volume, modes and intensity of exercise conditioning undertaken by patients as it had been regulated by clinical need. Clinical notes and hospital records, patient diaries, and evaluation of the 7D-PAR (see p. 186), were used to record patients' attendance at physiotherapy appointments (see p. 350). They were used also to record the amount of structured hospital-, home- and leisure-based rehabilitation performed by patients within two intervention arms (see p. 349). Inter-patient and inter-group differences in the dosage of rehabilitation might have affected the responses recorded within the study, hindering the correct attribution of any potential effects by the PPM intervention.

As shown in **TABLE 67** (p. 350), routine physiotherapy appointments and visits attended were similar for patients in both PPM and CON conditions up to 3 months post-ACLR surgery (confirmed by independent T-test). The number of routine appointments was recorded until each patient was discharged from the rehabilitation centre, as per hospital policy. It could be speculated that the reason for the greatest changes in attendance during the acute phase of rehabilitation was due to the fact that population studied were not professional athletes and most patients had returned to their full-time employment between 6 and 12 weeks post-surgery (Darain et al., 2015).

The content and volume of structured hospital-based physical rehabilitation as prescribed was monitored and recorded throughout routine physiotherapy appointments for a large portion of participants (31/46 patients). The total amount of work recorded during each routine physiotherapy appointment (structured hospital-based physical rehabilitation) was computed by calculating the number of exercise repetitions performed * number of sets performed per exercise * resistance weight (kg) lifted * duration (time) of exercise (Heijne and Werner, 2007). Subsequently, metabolic equivalents (MET) of energy expenditure were also calculated for each session, and using computed MET values it was possible to compute variables into calories per kg of body weight used per day (Kilo-calories/day).

For **Study 4 (Chapter 7: RCT intervention)**, home-based (and leisure-based) physical rehabilitation was only assessed at four time-points across the experimental period using the 7D-Recall P-BOM using memory recall. Although patients' self-reporting of physical activities is a useful insight, the literature often suggests that measures of self-report have the capacity to over- or underestimate true physical activity, energy expenditure, and rates of inactivity. Moreover, methods of self-report often have issues with memory recall and response bias (e.g. social desirability, inaccurate memory) and are at times unable to capture the true level of physical activity performed (Prince et al., 2008). Nevertheless, using these methods, the content and volume of physical rehabilitation was essentially matched and apparently had similar potential influence on outcomes throughout the experimental period for patients under PPM and CON rehabilitation group conditions.

Whilst the content and volume of physical rehabilitation was essentially equivalent throughout the experimental period, a limitation of the study was that it had been presumed and not directly assessed in all participants, that the patient's and physiotherapist's interaction, which occurred within the initial assessment phase of each physiotherapy appointment, was also matched between rehabilitation group conditions. The observed equivalency of each patient's periodic evaluation (including the total time for the introduction of the performance profile) of routine physiotherapy appointments, the total time for the initial introduction of the performance profile and periodic evaluations over the rehabilitation period, were the best estimates of whether patient-physiotherapist 'interaction' had been 'matched' for the time in discussion (an average of 30 minutes per physiotherapy appointment, see below).

Future research would require more accurate time-keeping records from the patient's and clinician's perspective to monitor actual time spent rehabilitating the knee, and particularly accounting for the time spent in the negotiation process being conducted. Nevertheless, total duration of physiotherapy appointments (structured hospital-based physical rehabilitation) in both groups during the rehabilitation period was the same (an average of 30 minutes per physiotherapy appointment). Therefore, with all this in mind, the implementation of the Performance Profiling technique in conjunction with a physiotherapist allowed a suitable and controlled setting to evaluate a different framework for patients' self-perceived needs, and within a more structured patient-centred approach. Previous research reported that approximately 75 minutes from a total of 700 minutes of structured hospital-based physical rehabilitation over a 6-month period was reported to be used in patient and physiotherapist interaction for negotiation purposes (RJAH, 2007). The PPM intervention had limited its time pragmatically to this latter period. In accordance with the rehabilitation centre's policy, each new patient following ACLR surgery was allocated one hour for his or her first routine appointment. This was to ensure a full and comprehensive subjective and objective assessment was conducted. For the introduction and elicitation stages of the Performance Profile, each patient constructed an individual Performance Profile based on their self-perceived needs within a two-week period prior to surgery. The construction of this profile was conducted on a voluntary basis, requiring each participant to attend an individual consultation approximately 7 to 13 minutes' long to achieve a finalised Performance Profile. It could be speculated that the time spent constructing a Performance Profile could be easily fit into each patient's initial physiotherapy appointment. Likewise, routinely-deployed P-BOMs similarly used (e.g. IKDC) to evaluate patients' perceived dysfunction or disability, could be exchanged for the Performance Profile, as the time required to complete a single Performance Profile is less than with other commonly-used ACL P-BOMs **(TABLE 58**; p. 305**)**. Arguably, the incorporation of the Performance Profile would be similar to the physiotherapist's routine current assessment approach. Only the structure of the discussion would differ, whereby the Performance Profile Management approach would be offered as a more systematic framework for discussion. Patients can complete a single performance profile quickly (2-3 minutes), with initial familiarisation and elicitation stages for the profiling methodology taking no longer than 15 minutes to complete. For the thesis, quantification and verification of the time spent administering the Performance Profile was necessary to understand its patient-friendliness (acceptability) and clinician-friendliness (practical feasibility) within a clinical setting. Here, when assessing the clinical utility of the Performance Profile in terms of the patient's administration, it is important for the Performance Profile to be completed in a relatively short period of time; the questions asked were clear, concise and easy to understand from the patient's perspective. From the clinician's perspective, the Performance Profile should require minimal effort and costs to administer, record and analyse. A full discussion of the practical utility of the profiling approach has been presented elsewhere (see p. 309).

In addition, repeated administrations of the Performance Profile would only require a new self-assessment of self-perceived needs that had been previously elicited. As identified in Study 3 **(Chapter 6: Reliability investigation)**, the time required to complete subsequent Performance Profiles was found to be 1:18 to 3:38 minutes, further suggesting that the Performance Profile may be a quicker method of assessment compared to traditional P-BOMs following the initial introduction and elicitation period. Three of the six administrations of the Performance Profiles for the reliability investigation **(Study 2)** were completed at home.

The delivery of the Performance Profile for Study 4 **(Chapter 7: Intervention RCT investigation)** comprehensively evaluated the injured and non-injured limbs separately, and additionally evaluated the relative importance of each quality within each patient's Performance Profile. It was necessary for the deployment of the PPM rehabilitation group condition **(Study 4: Intervention RCT Investigation)**, that the five areas identified as most important from the patient's perspective (as ascertained by the patient's importance ratings) would be used to initiate discussions between the patient and physiotherapist concerning how best to achieve the desired improvements from the patient's perspective, as these self-perceived needs were considered most important to them. It could be speculated that delivery of the PPM could be reduced in terms of patient involvement, and subsequently the associated administration times could be considerably reduced. Noteworthy too, following the serial completions of Performance Profile's post-ACLR and throughout 24 weeks of rehabilitation within each of the routine physiotherapy appointments attended, the time taken to complete the Performance Profile was dramatically reduced with increased practice and familiarity with the technique (data not shown).

The experimental design of Study 4 **(Chapter 7: Intervention RCT Investigation)**, meant that patients had the opportunity to revise the Performance Profile by adding more pressing concerns at the time of its administration at each routine visit. Within this process, the adding of additional qualities would help the physiotherapist understand any new and relevant concerns that had transpired from the patient's perspective. The Performance Profile was deployed throughout a 24-week period following ACLR surgery and administered prior to each physiotherapy appointment within this rehabilitation period. Contemporary clinical practice has dictated that the assessment and monitoring of patients by more traditional P-BOMs (i.e., IKDC, Lysholm and Cincinnati) would not have occurred more frequently than the deployment of the Performance Profile within Study 4 **(Chapter 7: Intervention RCT Investigation)**. Monitoring of patients' perceived capabilities by the Performance Profile might have been less frequent to match that of contemporary practice. Regardless, the integrated monitoring of the effectiveness of the intervention involving Performance Profile is the first attempt to systematically deploy the Performance Profile within any symptomatic populations in this context. It has acted as a pilot for its use within a patient-physiotherapist negotiation and management programme of rehabilitation (enhanced, structured patient-centred approach).

Anecdotally, the physiotherapist deploying the Performance Profile found that using the technique within the first consultation appointment was particularly useful in helping patients to become more self-aware of their injury, and provides patients with a useful mechanism for recording all their concerns for later discussion. Furthermore, in the context of this RCT **(study 4)**, the physiotherapist was an integral partner in the construction and discussion of patients' Performance Profiles, therefore future research would need to specifically evaluate physiotherapists' perceptions of the technique's usefulness. Further research may also want to evaluate the level of patient-centredness between patient and physiotherapist. It would be particularity useful to have examined patients' and clinicians' perspectives between both intervention arms (i.e., PPM and CON) to note any differences between them. The aim of patient-centred care is to ensure a person is an equal partner in their rehabilitation. At the present time there are many outcome measures available to evaluate patient-centredness, which generally report on a range of subscales from holism, power and empowerment, personalisation, choice and autonomy, empathy and compassion (Hudon, Fortin, Haggerty, Lambert, and Poitras, 2011). Several outcome measures evaluated by patients could have included: Patient Perception of Patient-centredness (Reinders, Blankenstein, Knol, de Vet, and Van Marwijk, 2009), Patient-centred Inpatient Scale (Davis, Byers, and Walsh, 2008), Patient-centred Care Scale (Terrien, Anthoine, and Moret, 2012).

Study 4 **(Chapter 7: Intervention RCT investigation)** has provided the first attempts to evaluate the efficacy and clinical utility of the Performance Profile within the confines of a relatively controlled setting. Standardisation of ACLR surgical procedures and well-prescribed ACL protocols has potentially provided a suitable clinical environment to empirically examine the Performance Profile approach in comparison to contemporary clinical practice (Doyle et al., 1998). Moreover, due to the patient sample (see below) and the high number of ACL surgeries performed within the time-frame of the thesis, stringent inclusion and exclusion criteria were adopted (i.e., patients were excluded if concomitant injuries to the injured knee were present at time of surgery, or if they had previous knee injury or surgeries to the non-juried limbs, etc.) to offer additional robustness to the experimental design, whilst offsetting the associated clinical and statistical heterogeneity in the observed treatment effects that were beyond what would be expected by random error (West et al., 2010). Further to this, the inclusion of strict inclusion and exclusion criteria contributed meaningfully to the external validity of the thesis results (Rothwell, 2006; Kennedy-Martin et al., 2015).

The design and construction of the Performance Profile, and in particular the ease of interpretation and visual representation of patients' self-perceived needs, may allow more time to be devoted to clinical therapy, whilst adopting a more structured patient-centred programme of care. The Performance Profile requires time to be delivered correctly (introduction and elicitation of PP: 6.32 to 12.52 minutes]), and the current results indicate that it is comparable or quicker to some of the more traditional P-BOMs such as the IKDC, which is reported to take a total of 10 minutes to administer and 5 minutes to score (Collins et al., 2011) **(**see **TABLE 58**; p. 308**)**. However, an additional advantage of the Performance Profile over other P-BOMs is that the Performance Profile can be used as an assessment and management outcome measure concomitantly. The current literature suggests that patient-centred approaches are required to understand what is important to patients, and to provide practitioners with a precise measurement of patients' perceived needs, which can be deployed to appropriately justify clinical decision-making (Michener, 2011; Lavoie et al., 2001). Performance Profile construction offers ease of interpretation without formal scoring, facilitated by a visual representation of patients' needs. Due to its simplistic nature, the Performance Profile may be more suited for use within the time-pressured arena of clinical practice, whilst still being capable of adopting patient-centred delivery of care (Doyle et al., 1998).

Communication is considered a central component of Patient-Centred Care (Bensing et al., 2000; Cooper et al., 2009) and, more recently, the concepts of both patient-centeredness and the shared-decision making process have been advocated as the starting point for effective communication for the delivery of Patient-Centred Care (Ishikawa et al., 2013). Therefore, future research would be required to evaluate person-centred communication to explore the extent to which patients are active and involved in discussions; whether healthcare professionals encourage patients to express their needs, preferences and concerns; whether professionals monopolise the conversation and the extent to which patients feel engaged and valued. Several examples of such P-BOMs would include the Physician-Patient Communication Behaviours Scale and the Perceived Involvement in Care Scale. In addition, it would be of greater importance to evaluate the shared decision-making process which would involve patients and professionals communicating about potential care options, and professionals supporting patients to consider the possible consequences of options and the evidence available before arriving at informed preferences. Several examples of P-BOMs would need to be included, i.e. the Decision-making Involvement Scale (Miller and Harris, 2012) and Shared Decision Making Questionnaire (Simon et al., 2006). Lastly, evaluation of patient experience relating to patients' perceived care, including satisfaction with care received would be another interesting avenue of research to further elucidate and understand what is important to the patient (Waters, Edmondston, Yates, and Gucciardi, 2016).

8.1.5. - Limitations

While the Performance Profile does report limitations to its use with asymptomatic athletes (Weston et al., 2013; Gucciardi et al. 2009b) and is, notably, lacking empirical research to support its use, only recently has newer evaluative research clearly supported the earlier claimed uses, benefits and impacts of the practical usefulness of this technique from the perspective of athletes and sport-practitioners alike which, for many years, was lacking (Weston et al., 2010; Weston et al., 2011a; Weston et al., 2011b). Therefore, the principal aim of the thesis was to act upon the key recommendations for future research which has been suggested by significant contributors within this field of research (Doyle and Parfitt, 1997; Doyle et al., 1998; Gleeson et al., 2005; Weston et al., 2013), namely, that there be a call for robust empirical research, which has scientific merit, which will support the efficacy and utility of the Performance Profile and warrant its further use in research and in clinical and practical applications. Future research is required to continue in the same vein, to investigate the clinical efficacy and utility of the Performance Profile with symptomatic populations.

This research was much needed to substantiate earlier uses of the Performance Profile with asymptomatic athletes. With this in mind, a large majority of the published literature underpinning the use of this Performance Profile is, seemingly, inadequate. For example, some studies are primarily based on descriptive reflections within single case study designs, or include relatively small sample sizes within uncontrolled experimental designs, while others reflect the expertise of the sport-psychologist (Butler, 1989; Butler and Hardy, 1992; Butler et al., 1993; Jones, 1993; Dale and Wrisberg 1996), rather than experimentally investigating the psychometric utility of the performance profile (Doyle, 1998; Weston, 2005; Weston, 2008).

Within the literature review within this thesis, it has been shown that many new research avenues still require investigation and, as a consequence, the areas of research already investigated need to be further developed in order to understand the efficacy of the Performance Profile **(**see **APPENDIX 2**; p. 445**)** (Weston et al., 2013). Although the general areas of research are still warranted for both asymptomatic and asymptomatic populations, the discussion has reported future recommendations accordingly.

This thesis incorporated the use of the contra-lateral limb as a control condition. When attempting to identify levels of 'normal' or improved function brought about by ACLR surgery and subsequent rehabilitation, the use of the contra-lateral asymptomatic leg as a baseline and control is prevalent and indeed, was used in this way in the intervention **(Study 4: Intervention RCT investigation)** and was also evaluated within the correlation chapter **(Study 2: Correlation investigation)**, which in the latter is rarely evaluated (Sernert et al., 1999).

There are caveats to the unreserved use of the contra-lateral limb as a reference for the injured limb because of the potential for deconditioning associated with injury-related alterations to physiological loading, limb dominance discrepancies, and bilateral neurophysiological (de)conditioning (Gleeson 2008). Nevertheless, the notion of functional and performance symmetry between injured and non-injured limbs has been favoured in the literature (Borsa et al., 1998; Hopper et al., 2002; Ardern et al., 2010), with patients who demonstrate an acceptable level of symmetry (85% to 100%) [Ageberg et al., 2008; Ardern et al., 2010; Thomeé et al., 2011] being considered more likely to return to sport (Fitzgerald et al., 2001; Ageberg et al., 2008; Ardern et al., 2010). Future research would be required to ascertain whether leg symmetry between injured and non-injured limbs was different between PPM and CON group conditions.

Although some physiological de-conditioning of this control leg's capabilities was likely to have occurred due to altered physiological loading in the period between ACL injury and ACLR surgery, it nevertheless represented a best estimate of a reference (baseline) performance capability (Gleeson et al., 2008; Bailey et al., 2015). As discussed, the inclusion of this control limb was particularly important within the findings in Study 4 **(Chapter 7: Intervention RCT investigation)**. For example, with regard to the non-injured limb associated with the HOP, unexpectedly, a two-factor ANOVA (leg [injured/non-injured] by assessment occasion [pre-surgery, 6, 12, and 24 weeks post-surgery]) reported a non-significant interaction [$F_{(2,88)}$= 0.1; *ns*]. This was suggesting perhaps (given a priori expectations of greater gains in the injured leg over time), that the performance of the 'control leg' (non-injured limb) was improving at the same rate as that of the injured leg. The bilateral improvement identified can potentially be attributed to the holistic (bi-lateral) nature of the ACL rehabilitation performed (Briggs et al., 2009). Similarly, PF, RFD, and EMD outcome measures also suggest this.

Furthermore, it is reasonable to presume that the non-injured limb post ACL injury suffered a degree of deconditioning prior to the pre-surgery assessment occasion. Further, following significant ACL injury/rupture, patients will have a reduced functional capacity in their normal daily activities of living, and refrain from sporting activity due to a number of reasons (Ardern et al., 2013). Initially this might be due to pain and swelling, followed by knee instability and/or fear of re-injury (Hopkins et al., 2000; Ardern et al., 2012a). Therefore, the post-operative period of rehabilitation is likely to show bilateral improvements and illustrates that a two-legged rehabilitation programme is required. Furthermore, the intervention of a pre-habilitation programme might limit deconditioning and provide earlier functional gains that would be insightful.

In order to assess the potential negative effects on the RCT experimental design of social approbation by the patients towards the test administrator (the author of this thesis), this research group **(**unpublished PhD thesis; Bailey, 2015) has previously evaluated the responses of an extra control group involving minimal test administrator-patient interactions. The findings showed that the patient's clinico-social approbation had not significantly intruded on the outcome of an RCT that had been similar in construction to that of the study undertaken in this thesis. The similarity between RCTs suggested that clinico-social approbation would not intrude on the findings of this thesis. Although, previous research has evaluated an extra control group deployed to investigate the influence of the test administrator occurring via patient and physiotherapy interactions associated with the assessment occasions, it would be appropriate to re-evaluate this manipulation check of patient's clinico-social approbation to ensure no influence was truly affected.

Moreover, it was appropriate logistically here to exclude this additional control group (as above) to optimise the experimental power of the study which only included two groups for comparison (i.e., PPM; CON). Anticipated sample numbers in PPM and CON rehabilitation group conditions were adhered to, ensuring acceptable levels of likelihood for the intrusion of type II error and associated miss-interpretation of findings (see sample size calculation; p. 197). Thus, with the proper management of likelihood of Type II error rates, any differences in response between the novel intervention and contemporary care practice (**Study 4: Intervention RCT investigation)** should be reasonably representative of what might be expected from variations from NHS care pathways associated with ACLR.

Post-ACLR surgery, all patients were treated by the same physiotherapist for the duration of their rehabilitation period with partial-blinding to intervention allocation and assessments occasions (conducted at pre-surgery, 6, 12 and 24 weeks post-surgery). During the experimental period, it was impossible to fully-blind the physiotherapist and research assessor (author of thesis) to altered characteristics of tissue scarring following ACLR surgery. The busy logistics of care delivery to patients within the NHS, meant that realistically, those individuals involved in the experimental delivery had little additional time to offer attention and the potential for unwanted bias. Double-blinding was not achieved in this study and this may be considered as a limitation. In Study 4 **(Chapter 7: Intervention RCT investigation)**, patients were blinded to the treatment/rehabilitation. However, blinding of the physiotherapist and assessor was not feasible due to the educational nature of this research and associated budget-limitations. Similarly, individuals involved in data analysis were not blinded to some aspects of the data (testing occasion and group allocations) and this may have contributed to bias in the results.

8.1.5. - Future research

Given that the intervention potency for the PPM of rehabilitation had not been 'optimised' within this study, with PPM essentially being used as a conduit for the initiation of relevant discussion amongst patient, physiotherapist and clinician (rather than a formal method for establishing the intensity of conditioning), the observed effects for PPM may have been muted compared to what might have been achieved. Despite its RCT-nature and characteristics, this study had essentially been a 'pilot' investigating 'real-world'/pragmatic clinical efficacy for PPM. That is, it had fallen between being a study investigating the clinical efficacy of PPM (involving optimised clinical conditions to elicit maximum effects in outcome measures), and being a study of clinical effectiveness, involving commensurate delivery of the intervention within the 'real-world' environment associated with the NHS, and perhaps involving multiple centres of care-delivery.

For the first time, PPM appears to have offered an approach to musculoskeletal rehabilitation following surgery that matches the effectiveness of current clinician-led delivery, which most importantly, uses an approach that systematically focuses on individualised care. As such, the physiotherapist or clinician has a viable choice in the delivery of rehabilitation. Future research would be expected to refine and evaluate how best to use the mechanisms of PPM delivery to offer a titration of the intensity of exercise conditioning and facets of rehabilitation to optimise care for each individual patient. It is also paramount that patients could in fact identify the five most important self-perceived needs accurately, as this importance of items would be used to initiate discussion between patient and physiotherapist. In fact, if patients could not accurately identify relevant importance of profile items, this may have consequences for subsequent discussions between the patient and physiotherapist **(Study 4: Intervention RCT investigation)**. With regards to the timing data for the ranking of relative importance of self-perceived needs, it could be expected that this time spent ranking the relative importance of attributes would be considerably reduced if only the five attributes considered most important were needed, as opposed to all participants ranking each profile item as evaluated here.

Although patient self-report on physical activities is a useful insight, the literature suggests often that measures of self-report have the capacity to over- or underestimate true physical activity, energy expenditure, and rates of inactivity. Moreover, methods of self-report often have issues with memory recall and response bias (e.g. social desirability, inaccurate memory) and are at times unable to capture the true level of physical activity performed (Prince et al., 2008). Nevertheless, using these methods, the content and volume of physical rehabilitation was essentially matched and apparently has similar potential influence on outcomes throughout the experimental period for patients under PPM and CON rehabilitation group conditions.

Therefore, future research would be required to investigate in greater detail, the amount of physical activity and rehabilitation performed throughout the entire rehabilitation period, to establish a more accurate evaluation of patients' rehabilitation conducted away from the rehabilitation centre. Determining the frequency, intensity and duration of exercises within each patient's physiotherapy appointments would be an important factor to consider for controlling the heterogeneity of exercise prescribed throughout the experimental period.

As with previous research, Butler (1989) also sought to understand not only the perspective of the athlete in terms of what the athlete considered important, but to understand the importance and consideration of the coach's perspective of the athlete's performance and areas in need of improvement also. This is achieved by the coach separately rating the same qualities the athlete perceives to be important (Dale and Wrisberg, 1996; Weston et al., 2010; Weston et al., 2011a). Similarly, future research would be required to evaluate the physiotherapist's responses to patients' own profile items. The patient and physiotherapist may view rehabilitation and goals differently. In turn, the physiotherapist may not accommodate the perceived needs of the patient, resulting in frustration by the patient. In addition, areas resistant to change, in particular, areas that the patient perceives not to be as important compared to the views and opinions of the physiotherapist could, therefore, impact on the levels of patient-centeredness between patient and physiotherapist. Nevertheless, utilising a physiotherapist's perspective of patient profile items combined with the importance of the items would facilitate discussions points.

A newer proposed and extended version might offer researchers and/or practitioners a means to further understand the content and structure of the individual's perspective and may be useful in developing a greater variety of interventions or guiding novel one-to-one consultations (Gucciardi and Gordon, 2009a; Gucciardi and Gordon, 2009b). This new profiling procedure, which would utilise many of the underpinning theories associated with the Personal Construct Theory, should parallel the original construction of the Repertory Grid technique. The original Performance Profile was adapted so that this approach could be completed quickly. At the same time, it provided athletes (and now patients) with a display of information, which can be interpreted visually, in order to understand the athlete's self-perceived strengths and weaknesses quickly, without the logistical challenges of numerical interpretations that were required with the Repertory Grid technique (Butler et al., 1993). It could be argued that the methodological procedures of Gucciardi and Gordon (2009a) have been more time-intensive to construct and analyse. As yet, their extended profiling procedure has not yet been scientifically and empirically tested or evaluated against the original profiling procedures of Butter and Hardy (1992) in order to verify its efficacy (Weston et al., 2013). Future research would be required to evaluate other variations of the Performance Profile within clinical settings. Further evaluation of Gucciardi and Gordon's (2009a) procedures, despite their time-intensive nature, may provide requisite clinical potency.

While the Performance Profile does report limitations to its use with asymptomatic athletes (Weston et al., 2013; Gucciardi et al., 2009) and is, notably, lacking empirical research to support its use, only recently has newer evaluative research clearly supported the earlier claimed uses, benefits and impacts of the practical usefulness of this technique from the perspective of athletes and sport-practitioners alike which, for many years, was lacking (Weston et al., 2010; Weston et al., 2011a; Weston et al., 2011b). More so, with the recent transference of the Performance Profile to a clinical setting, this thesis represents the first study to investigate the use of the Performance Profile among patients, with it previously only being advocated within athlete-based research and within this athletic population, despite the fact that only one randomised trial has been used to investigate this management tool with athletes (Weston et al., 2011b).

Weston et al. (2011b) provides the only experimental study to examine the impact of repeated profiling sessions on athlete intrinsic motivation. Moreover, the findings here suggested that a single use of the Performance Profile failed to significantly improve athlete intrinsic motivation, however, following three repeated completions during a competitive season of six weeks' duration, intrinsic motivation improved significantly compared to the control group condition. These findings should be viewed cautiously. However, this first attempt to investigate the motivational responses of performance profiling to enhance motivation is encouraging. This research was much needed to substantiate earlier uses of the Performance Profile with asymptomatic athletes. With this in mind, a large majority of the published literature underpinning the use of this Performance Profile is, seemingly, inadequate. For example, some studies are primarily based on descriptive reflections within single case study designs, or include relatively small sample sizes within uncontrolled experimental designs, while others reflect the expertise of the sport-psychologist (Butler, 1989; Butler and Hardy, 1992; Butler et al., 1993; Jones, 1993; Dale and Wrisberg, 1996), rather than experimentally investigating the psychometric utility of the Performance Profile (Doyle et al., 1998; Weston, 2005; Weston, 2008). Future research would be warranted to examine the effects of the Performance Profile on patient motivation and adherence to rehabilitation.

Investigating the use of the Performance Profiling approach at a single rehabilitation centre and utilising only one physiotherapist would limit the external validity of the thesis' findings. Future investigations would need to consider the delivery of the Performance Profile within a multi-centre environment to confirm the wider applicability of this study's exploratory findings, with multiple physiotherapists adopting the profiling techniques and associated procedures. In the latter, the physiotherapist involved within RCT **(Study 4)** was considerably experienced in the rehabilitation of the knee joint, with 14 years' experience in ACL injury and rehabilitation. However, it would be equally important to examine the personality traits, communication styles and physiotherapists' approaches to care delivery, level of experience, and the physiotherapy approaches (i.e., protocol-based approach, clean slate approach, and systematically reassessing a patient's progress with the management plan being modified accordingly) (see Tuttle, 2009). These aspects could potentially be important contributors to the patient-physiotherapist relationship and underpin patient-centred care.

8.2 - Thesis conclusion

The primary aim of this thesis was to investigate whether or not novel delivery of patient-centred musculoskeletal, post-surgery rehabilitation offers an improved clinical outcome compared to current practice. This aim was evaluated using a wide variety of P-BOMs and C-BOMs. In order to achieve this aim, an objective, involving the delivery of a clinical RCT was set **(Chapter 7: Intervention RCT Investigation).** The overall finding associated with the thesis' primary aim was that encouraging patients to self-perceive and manage areas of physical need within their standardised rehabilitation elicited clinical outcomes which at least matched those of contemporary practice, which under some circumstances exceeded its patterns of patient recovery.

These overall primary aim findings from the research promoted understanding of individualised patient needs and described the circumstances in which rehabilitation might be enhanced. For the first time, PPM appears to have offered an approach to post-surgery musculoskeletal rehabilitation that matches the effectiveness of current clinician-led delivery, and which most importantly, uses an approach that systematically focuses on individualised care. As such, the physiotherapist or clinician has a viable choice in the delivery of rehabilitation.

Future research would be expected to refine and evaluate how best to use the mechanisms of PPM delivery to offer a titration of the intensity of exercise conditioning and facets of rehabilitation to optimise care for each individual patient.

The results presented from the clinical RCT **(Study 4: Intervention RCT Investigation)** evaluating the novel application of Performance Profile have shown that patients following both PPM[150] and CON[151] rehabilitation programmes demonstrated improved performance (i.e., Single-Leg Hop for distance, ATFD, IKDC, KOOS, Lysholm, Performance Profile, SMP-FE [knee flexors]), PF, EMD, and RFD) to a similar extent over time (24 weeks). However, PPM elicited superior (1.2%) SMP-FE (knee extensors) performance compared to CON practice clinical effectiveness ($F_{(2.5,113.7)GG} = 3.2$, $p< 0.05$). This was a prominent finding because of Sensorimotor Performance's causal linkage to ACL injury (Silvers and Mandelbaum, 2007; Ettlinger et al., 1995; Myklebust et al., 1998; Caraffa et al., 1996; Hewett et al., 2006; Griffin et al., 2006).

Study 4 supports the deployment of the Performance Profile with patients suffering ACL deficiency and undergoing reconstructive surgery with rehabilitation, as a means to evaluate individualised patients' perceptions of functional capability. The results provide initial support for the introduction of the Performance Profile to clinical practice with minimal additional logistical costs, since delivery of both PPM and CON practice are iso-volumetrically, logistically and cost equivalent. Importantly, this novel form of PPM rehabilitation was well tolerated by patients, and patterns of change in knee functional capability during post-ACLR showed equivalent improvements with the Performance Profile and other frequently-used P-BOMs and C-BOMs. Indeed, PPM may be a suitable medium to initiate patient-centred approaches during post-surgery musculoskeletal rehabilitation and may facilitate the understanding of patients' self-perceived needs. In fact, the time required for introduction, delivery and re-administration makes the Performance Profile a viable assessment (and rehabilitation management) tool that may be much quicker and more cost-effective to deliver than traditional P-BOMs (for example, IKDC which requires a total of 15 minutes to administer and score over the equivalent period).

[150] Performance Profile Management (PPM).
[151] Contemporary (CON) clinical practice.

Other objectives within the thesis that addressed its primary aim included:

Study 1 **(Chapter 3: Systematic Review of the literature)** was an objective for the thesis that offered a novel attempt to systematically evaluate relationships amongst P-BOMs and C-BOMs concomitantly within an ACL-deficient population. A total of twenty-six P-BOMs and forty-six C-BOMs were found during the reviewing process, illustrating the diversity of outcome measures available to assess study outcomes. For this reason, the studies were mostly non-comparable with no same P-BOM being consistently evaluated with the same C-BOM. Approximately 9% of all relationships found (36/388) were statistically significant ($p < 0.05$) and few demonstrated potential clinical relevance ($r \geq 0.70$). Unfortunately, the outcome of this study does not support the single use of one P-BOM and/or C-BOM at pre-surgery, or across the acute, intermediate and late phases of rehabilitation, and up to 5 years post-ACL injury or 5 years post-ACLR surgery as a means of accurately reflecting knee performance with ACL deficiency.

Study 2 **(Chapter 5: Correlation investigation)**, was another intermediate objective for the thesis which offered evidence for relationships amongst a selection of P-BOMs and C-BOMs frequently used in clinical practice, together with the Performance Profile. When these outcomes were measured simultaneously within a single clinical population, results showed that overall, there was a lack of statistically (317/2808 [11%]) and clinically-relevant ($r \geq 0.70$) correlations (39/2808 [1.4%]) amongst P-BOMs, amongst C-BOMs, and between P-BOMs and C-BOMs. Moreover, Performance Profile appeared infrequently/sporadically among all three aspects of inter-correlation analyses at pre-surgery/rehabilitation. The proxy use of a P-BOM (including Performance Profiling) to replace time- and cost-intensive C-BOMs was not supported. Importantly, the lack of correlation among P-BOMs and C-BOMs could potentially lead to sub-optimal conditioning within rehabilitation therapy, with patients' perceived capabilities being mismatched to the objectively-derived measurements. Furthermore, each P-BOM/C-BOM might be contributing to the assessment of a separate, but potentially important aspect of function and recovery, therefore, clinical practice/research should continue to deploy a battery of P-BOMs/C-BOMs to holistically evaluate patients' functional and physical capabilities. Physiotherapists should thus avoid promoting a patient rehabilitative regime using evaluations of progression and improvement based on a single outcome measure. However, the minimum number of P-BOMs and/or C-BOMs required to properly describe changes in functional or physical performance within a multivariate format is not yet known, and it is unclear whether P-BOMs or C-BOMs offer most clinical validity.

Lastly, Study 3 **(Chapter 6: Reliability study),** investigating selected psychometric qualities of Performance Profile, showed that Study 3 was the first investigation to evaluate the Performance Profile's reliability characteristics in a symptomatic population following ACL injury and ACLR surgery. Patients were familiarised and accommodated rapidly to the Performance Profile and intra-subject changes in Performance Profile scores over days could be attributed to random variability, rather than to systematic learning effects. The first five self-perceived needs rated most important provided slightly inferior reproducibility, but similar single-measurement reliability compared with the first ten and fifteen self-perceived needs rated most important. Measurement errors were five-fold greater for the injured leg compared to the non-injured limb. Measurement responsiveness from pre- to post-ACLR surgery supports the Performance Profile's capability to detect changes in performance of the injured limb (3.34-unit reduction [57.7% reduction compared to baseline at pre-surgery]). Performance Profiling thus demonstrated suitable psychometric measurement reliability and reproducibility for inclusion within the RCT **(Study 4: Intervention RCT Investigation)**. The Performance Profile can be applied immediately in a clinical setting (and other symptomatic populations), without extra cost.

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APPENDICES

CONTENTS

APPENDIX 1

TABLE 71 - Post-operative ACLR reconstruction regime Sports Injury Surgery, Oswestry (see RJAH, 2007).

PHASE OF REHABILITATION	STAGE OF PTG REMODELLING	IDEAL CRITERIA	REHABILITATION GUIDE	GOALS
PHASE 1 **Day 1 - Discharge**	The graft is at its strongest at this stage, with respect to the soft tissue.		CPM as tolerated Cryocuff/ Ice. Patella mobilisations. EOR E mobilisations Hamstring (H) and calf stretches. Ankle exercises. Passive F over edge of bed. Static quadriceps (Q). Co-contraction Q and H. Avoid 'heavy' eccentric Q, which may overload the harvest site. Prone H, con/ecc/isomet. Prone SLR. PWB with elbow crutches to comfort. Cricket splint in situ for first week to reduce haemorrhage and prevent intracondylar notch scarring. Can be removed for exercises and sleep. Mini squats. Heel raises. Weight transferring.	Reduce inflammation. Gain full terminal E Promote distal circulation. Gradually regain ROM. Introduce early Q/H work. Promote early mobility.

PHASE OF REHABILITATION	STAGE OF GRAFT REMODELLING	IDEAL CRITERIA	REHABILITATION GUIDE	GOALS
PHASE 2 **Discharge - 10 Days**	No initial blood supply to graft, results in avascularisation of the soft tissue aspect.	Full active and passive E. Mobilise independently +/- aids.	Static bike no/low resis. as tolerated. Gradually increase weight bearing. Gait re-education (wean off splint and elbow crutches). Low step-touch→step up. Active OKC Q 90°-45°. Progress H work re: Reps/Resis, as able. Other muscle groups not to be neglected.	Promote early function. Increase ROM. Encourage weight bearing. Improve muscular strength/endurance and control.

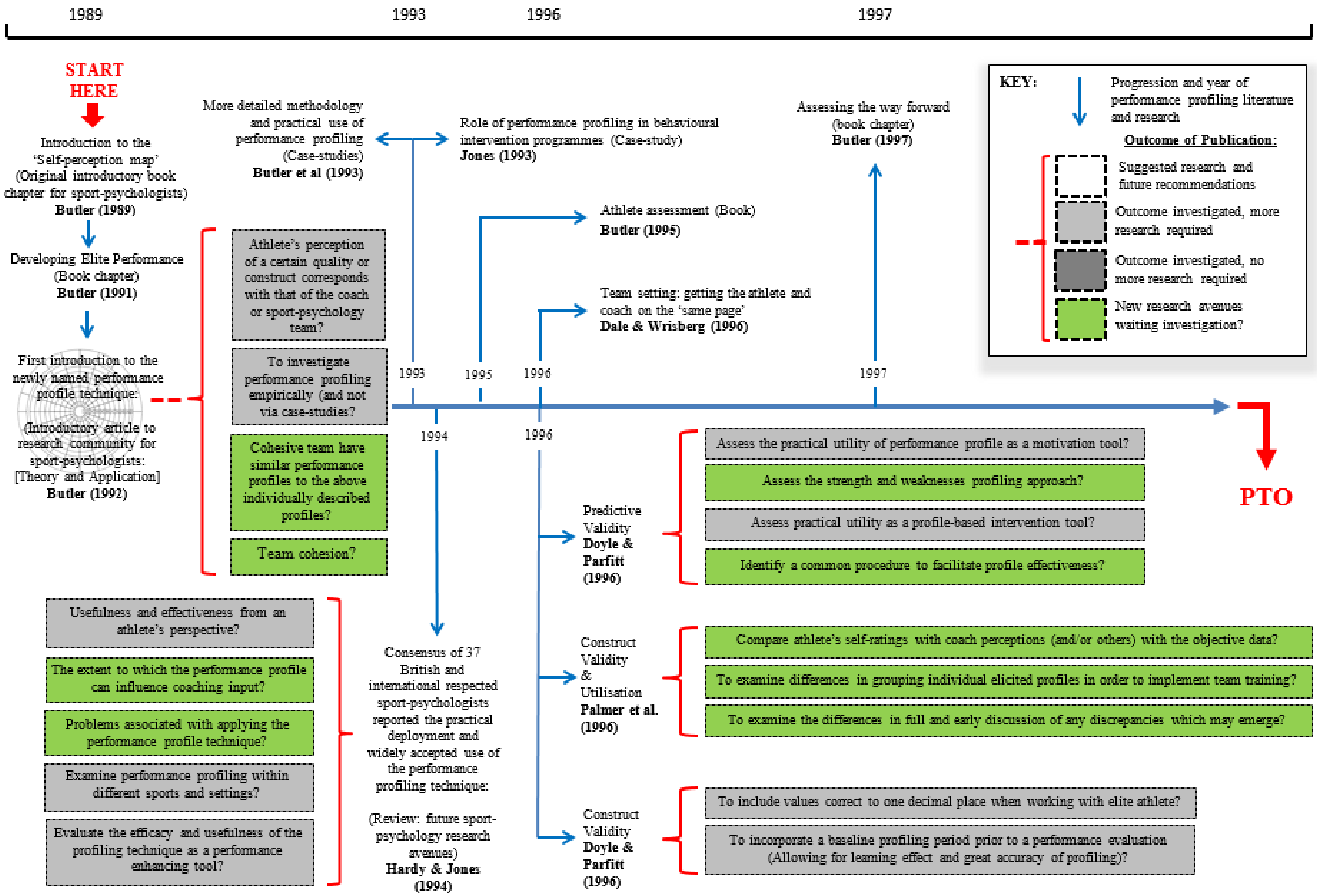
PHASE OF REHABILITATION	STAGE OF GRAFT REMODELLING	IDEAL CRITERIA	REHABILITATION GUIDE	GOALS
PHASE 3 **Day 10 - Week 6**	Avascularisation of graft leads to continual decrease in graft strength. The graft becomes enveloped in a synovial sheath.	Minimal discomfort. SLR with no lag. AROM = Full E - 100°	FWB. Gait with predictable changes in direction. Prone auto-overpress F →develop Q stretch Step ups (for/back/sideways) →height/reps/resis/ speed. Leg press →reps/resis/speed. Early plyometrics. Rowing →dist/speed/resis. Progress proprioception →wobble boards/sit-fit/trampette/crash mats/etc. Gym ball, Theraband work Hydrotherapy/swimming (AVOID breaststroke legs until 3-month stage) Progress general leg exercises VMO, ab/adduction, gluteal, etc. Upper body. Muscle balance as appropriate. Flexibility as appropriate.	Progress functional activities. Prevent anterior knee pain. Prevent scar adherence. Prevent joint stiffness Restore normal gait pattern. Promote appropriate muscle strength/power and endurance. Improve proprioception. Maintain cardiovascular fitness. Encourage patient compliance.

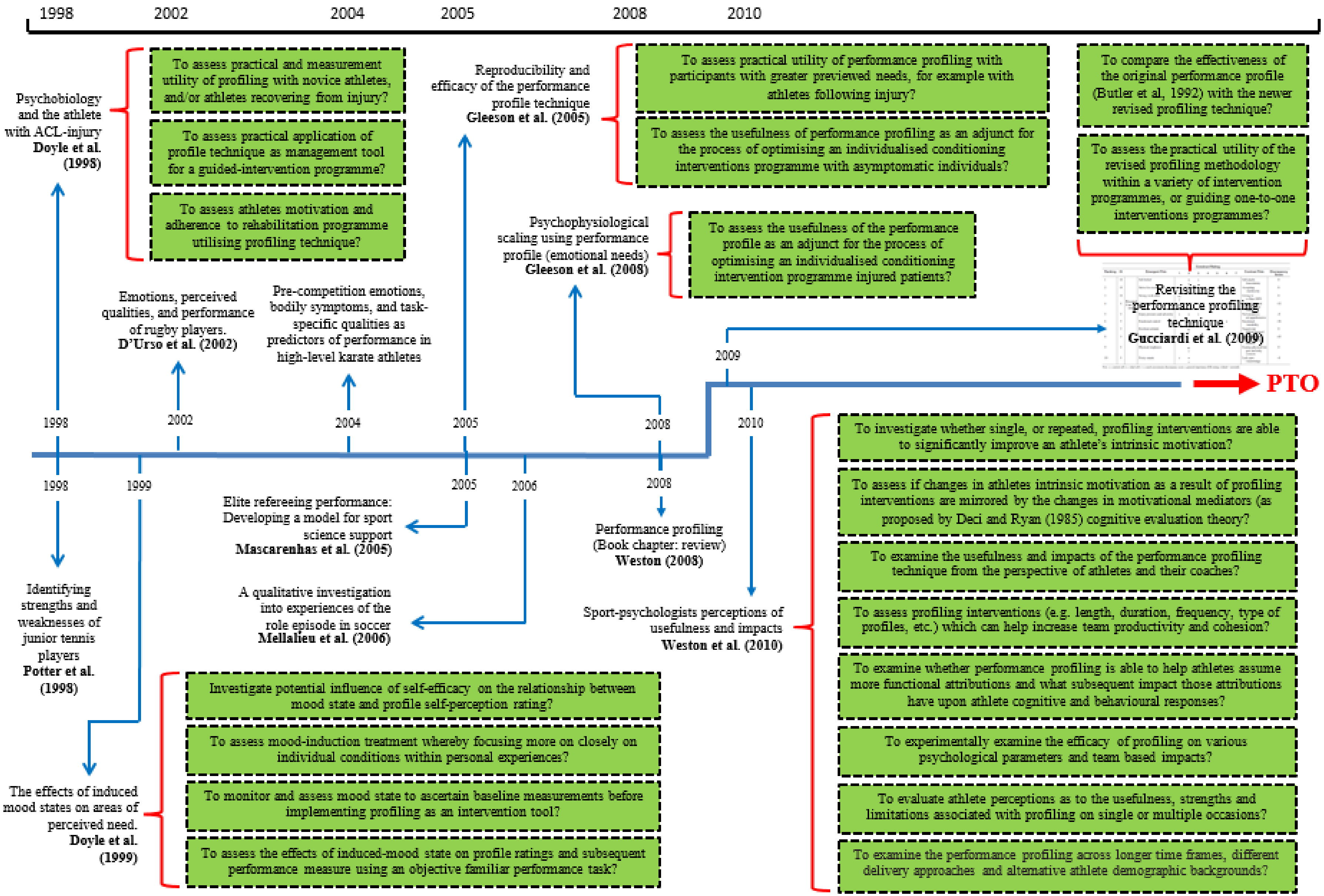
PHASE OF REHABILITATION	STAGE OF GRAFT REMODELLING	IDEAL CRITERIA	REHABILITATION GUIDE	GOALS
PHASE 4 **From Week 6-12**	Bone blocks unite with surrounding bone and revascularisation of the graft commences. An increase in graft laxity is usually apparent on testing between ~ week 10-12.	'Normal' gait pattern, pain free. Full ROM. 1 leg balance ~1 min.	Progress above as able. Trampette jogging. 'Power' walking .→duration/incline/ decline/cadence. Isokinetic H.	Continue to promote specific function. Increase muscle work and control through range. Isomet. Q strength = 75-85%.
PHASE 5 **From Month 3**	By month 4 complete revascularisation with the laying down of collagen occurs. A gradual increase in strength is gained as the graft remodels.	30 min. 'Power' walk. Row 2000m within 15 min., mod resis. H ~90% of contra-lateral side. Adequate dynamic proprioception.	Isokinetic Q. OKC Q →reps/resis/speed/con/ ecc/isomet. Plyometrics, drops from 6-18"/ bounding, etc. Hopping →stride/direction/stops/ speed. Jogging →Running Surface/distance Progress to incorporate: Agility, run/ sprint/cut/ pivot/ accelerate/ decelerate.	Bias to specific function/sport.
PHASE 6 **From Month 5**		Dependent on sport. 80-90% isomet. and isokin. Q strength of contra-lateral side. Proprioception ~90% contra-lateral side.	Non-contact training. Non-contact sport.	1. Prepare physical and psychological ability for complete return to unrestricted function.

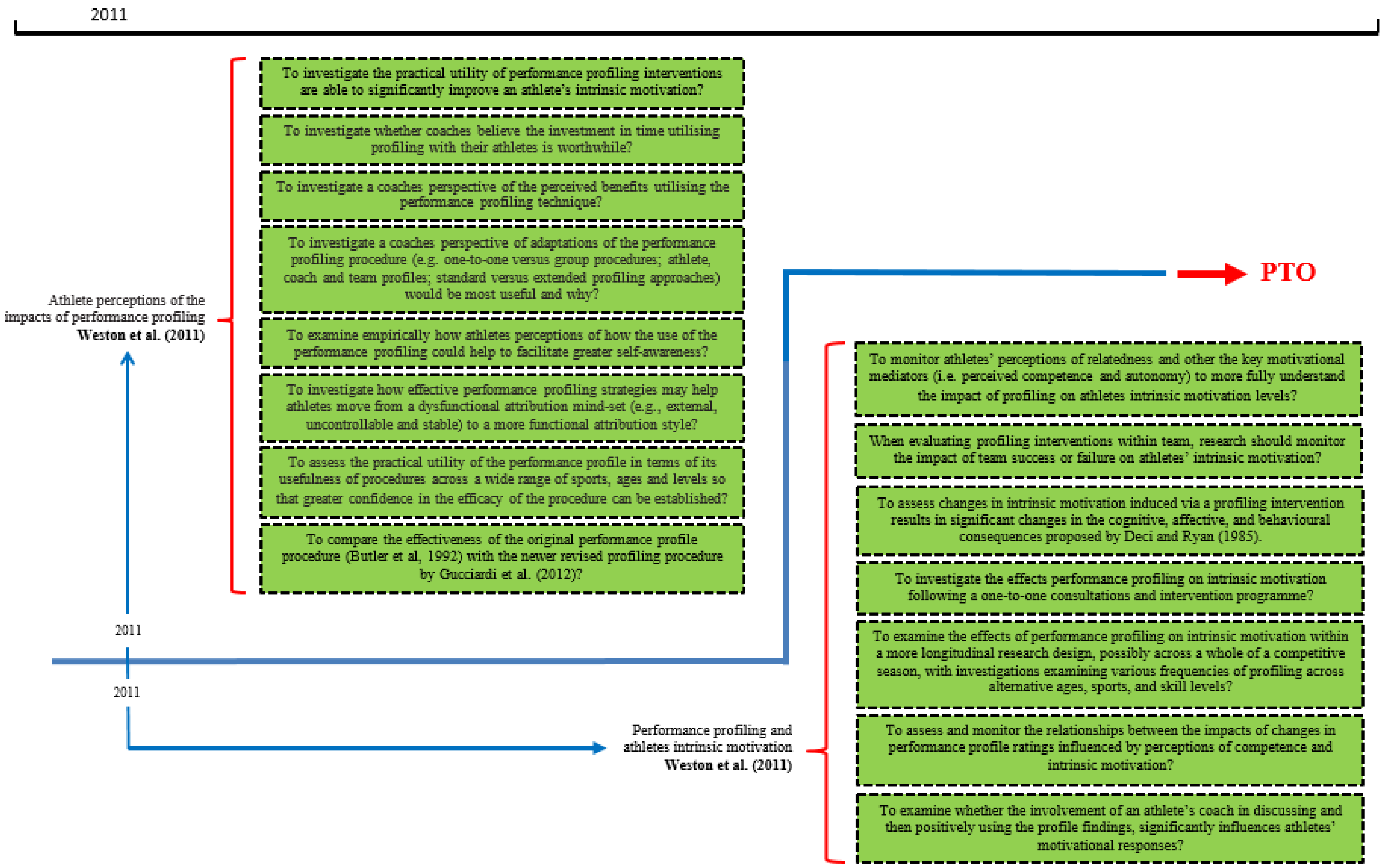
PHASE OF REHABILITATION	STAGE OF GRAFT REMODELLING	IDEAL CRITERIA	REHABILITATION GUIDE	GOALS
PHASE 7 **From Month 6**	Gradual organisation of collagen. At 1 year the graft resembles the appearance of a ligament with densely organised collagen bundles. Graft strength is thought to range from 30-60% of the original. The laxity of the graft appears to be linked with muscle strength.	Symptom free training. No residual complications. Psychologically prepared.	Earliest return to contact sport.	Unrestricted confident function.

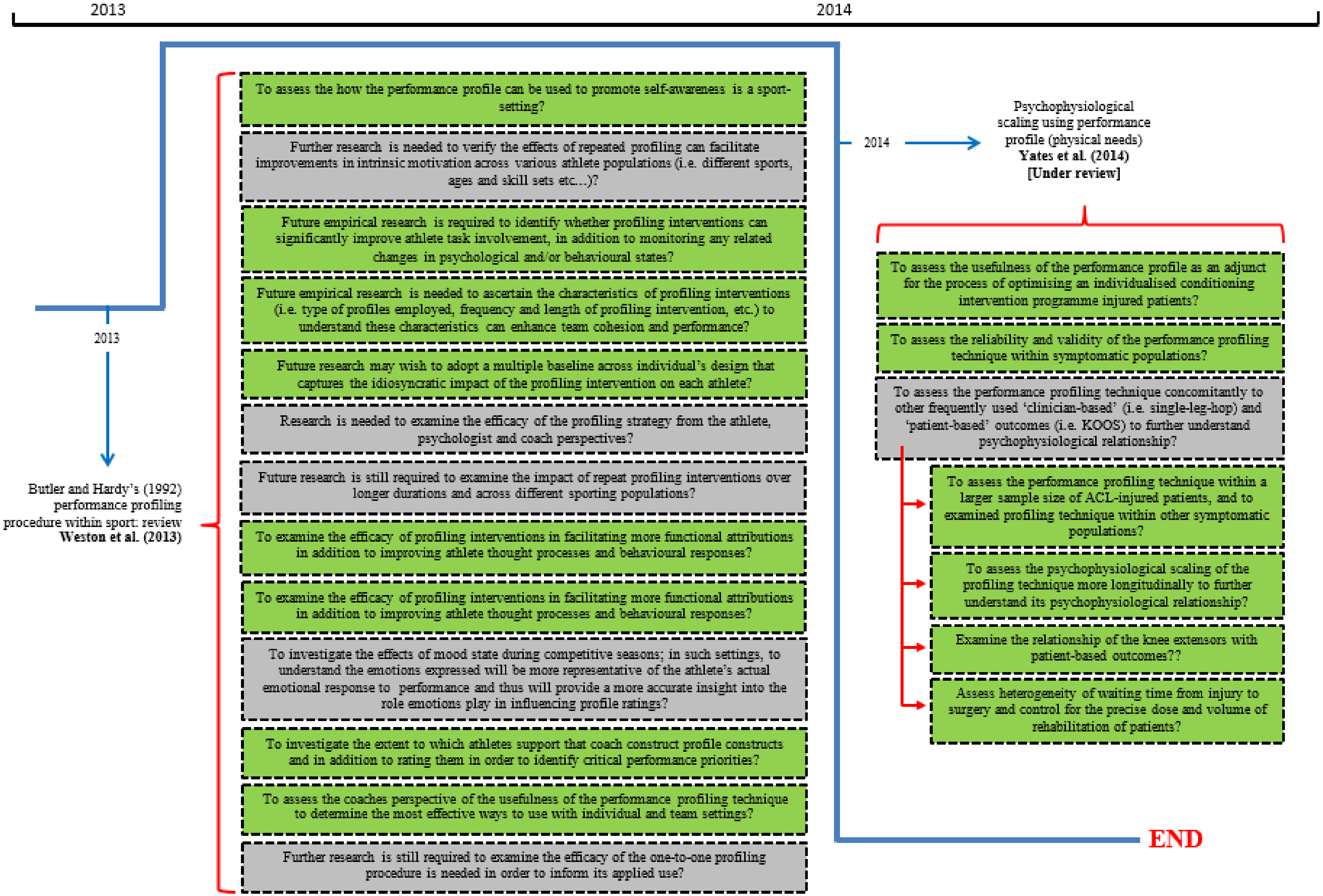
APPENDIX 2

Chronological flow diagram representing published Performance Profiling literature.




1998
2002
2004
2005
2008
2010
Psychobiology and the athlete with ACL-injury **Doyle et al. (1998)**
To assess practical and measurement utility of profiling with novice athletes, and/or athletes recovering from injury?
To assess practical application of profile technique as management tool for a guided-intervention programme?
To assess athletes motivation and adherence to rehabilitation programme utilising profiling technique?
Reproducibility and efficacy of the performance profile technique **Gleeson et al. (2005)**
To assess practical utility of performance profiling with participants with greater previewed needs, for example with athletes following injury?
To assess the usefulness of performance profiling as an adjunct for the process of optimising an individualised conditioning interventions programme with asymptomatic individuals?
To compare the effectiveness of the original performance profile (Butler et al, 1992) with the newer revised profiling technique?
To assess the practical utility of the revised profiling methodology within a variety of intervention programmes, or guiding one-to-one interventions programmes?
Psychophysiological scaling using performance profile (emotional needs) **Gleeson et al. (2008)**
To assess the usefulness of the performance profile as an adjunct for the process of optimising an individualised conditioning intervention programme injured patients?
Emotions, perceived qualities, and performance of rugby players. **D'Urso et al. (2002)**
Pre-competition emotions, bodily symptoms, and task-specific qualities as predictors of performance in high-level karate athletes
Revisiting the performance profiling technique **Gucciardi et al. (2009)**
2009
PTO
1998
2002
2004
2005
2008
2010
1998
1999
2005
2006
2008
Elite refereeing performance: Developing a model for sport science support **Mascarenhas et al. (2005)**
A qualitative investigation into experiences of the role episode in soccer **Mellalieu et al. (2006)**
Performance profiling (Book chapter: review) **Weston (2008)**
Sport-psychologists perceptions of usefulness and impacts **Weston et al. (2010)**
Identifying strengths and weaknesses of junior tennis players **Potter et al. (1998)**
The effects of induced mood states on areas of perceived need. **Doyle et al. (1999)**
Investigate potential influence of self-efficacy on the relationship between mood state and profile self-perception rating?
To assess mood-induction treatment whereby focusing more on closely on individual conditions within personal experiences?
To monitor and assess mood state to ascertain baseline measurements before implementing profiling as an intervention tool?
To assess the effects of induced-mood state on profile ratings and subsequent performance measure using an objective familiar performance task?
To investigate whether single, or repeated, profiling interventions are able to significantly improve an athlete's intrinsic motivation?
To assess if changes in athletes intrinsic motivation as a result of profiling interventions are mirrored by the changes in motivational mediators (as proposed by Deci and Ryan (1985) cognitive evaluation theory?
To examine the usefulness and impacts of the performance profiling technique from the perspective of athletes and their coaches?
To assess profiling interventions (e.g. length, duration, frequency, type of profiles, etc.) which can help increase team productivity and cohesion?
To examine whether performance profiling is able to help athletes assume more functional attributions and what subsequent impact those attributions have upon athlete cognitive and behavioural responses?
To experimentally examine the efficacy of profiling on various psychological parameters and team based impacts?
To evaluate athlete perceptions as to the usefulness, strengths and limitations associated with profiling on single or multiple occasions?
To examine the performance profiling across longer time frames, different delivery approaches and alternative athlete demographic backgrounds?


2011
To investigate the practical utility of performance profiling interventions are able to significantly improve an athlete's intrinsic motivation?
To investigate whether coaches believe the investment in time utilising profiling with their athletes is worthwhile?
To investigate a coaches perspective of the perceived benefits utilising the performance profiling technique?
To investigate a coaches perspective of adaptations of the performance profiling procedure (e.g. one-to-one versus group procedures; athlete, coach and team profiles; standard versus extended profiling approaches) would be most useful and why?
To examine empirically how athletes perceptions of how the use of the performance profiling could help to facilitate greater self-awareness?
To investigate how effective performance profiling strategies may help athletes move from a dysfunctional attribution mind-set (e.g., external, uncontrollable and stable) to a more functional attribution style?
To assess the practical utility of the performance profile in terms of its usefulness of procedures across a wide range of sports, ages and levels so that greater confidence in the efficacy of the procedure can be established?
To compare the effectiveness of the original performance profile procedure (Butler et al, 1992) with the newer revised profiling procedure by Gucciardi et al. (2012)?
Athlete perceptions of the impacts of performance profiling
Weston et al. (2011)
PTO
To monitor athletes' perceptions of relatedness and other the key motivational mediators (i.e. perceived competence and autonomy) to more fully understand the impact of profiling on athletes intrinsic motivation levels?
When evaluating profiling interventions within team, research should monitor the impact of team success or failure on athletes' intrinsic motivation?
To assess changes in intrinsic motivation induced via a profiling intervention results in significant changes in the cognitive, affective, and behavioural consequences proposed by Deci and Ryan (1985).
To investigate the effects performance profiling on intrinsic motivation following a one-to-one consultations and intervention programme?
To examine the effects of performance profiling on intrinsic motivation within a more longitudinal research design, possibly across a whole of a competitive season, with investigations examining various frequencies of profiling across alternative ages, sports, and skill levels?
To assess and monitor the relationships between the impacts of changes in performance profile ratings influenced by perceptions of competence and intrinsic motivation?
To examine whether the involvement of an athlete's coach in discussing and then positively using the profile findings, significantly influences athletes' motivational responses?
2011
2011
Performance profiling and athletes intrinsic motivation
Weston et al. (2011)


2013
2014
2013
Butler and Hardy's (1992) performance profiling procedure within sport: review
Weston et al. (2013)
To assess the how the performance profile can be used to promote self-awareness is a sport-setting?
Further research is needed to verify the effects of repeated profiling can facilitate improvements in intrinsic motivation across various athlete populations (i.e. different sports, ages and skill sets etc…)?
Future empirical research is required to identify whether profiling interventions can significantly improve athlete task involvement, in addition to monitoring any related changes in psychological and/or behavioural states?
Future empirical research is needed to ascertain the characteristics of profiling interventions (i.e. type of profiles employed, frequency and length of profiling intervention, etc.) to understand these characteristics can enhance team cohesion and performance?
Future research may wish to adopt a multiple baseline across individual's design that captures the idiosyncratic impact of the profiling intervention on each athlete?
Research is needed to examine the efficacy of the profiling strategy from the athlete, psychologist and coach perspectives?
Future research is still required to examine the impact of repeat profiling interventions over longer durations and across different sporting populations?
To examine the efficacy of profiling interventions in facilitating more functional attributions in addition to improving athlete thought processes and behavioural responses?
To examine the efficacy of profiling interventions in facilitating more functional attributions in addition to improving athlete thought processes and behavioural responses?
To investigate the effects of mood state during competitive seasons; in such settings, to understand the emotions expressed will be more representative of the athlete's actual emotional response to performance and thus will provide a more accurate insight into the role emotions play in influencing profile ratings?
To investigate the extent to which athletes support that coach construct profile constructs and in addition to rating them in order to identify critical performance priorities?
To assess the coaches perspective of the usefulness of the performance profiling technique to determine the most effective ways to use with individual and team settings?
Further research is still required to examine the efficacy of the one-to-one profiling procedure is needed in order to inform its applied use?
2014
Psychophysiological scaling using performance profile (physical needs)
Yates et al. (2014)
[Under review]
To assess the usefulness of the performance profile as an adjunct for the process of optimising an individualised conditioning intervention programme injured patients?
To assess the reliability and validity of the performance profiling technique within symptomatic populations?
To assess the performance profiling technique concomitantly to other frequently used 'clinician-based' (i.e. single-leg-hop) and 'patient-based' outcomes (i.e. KOOS) to further understand psychophysiological relationship?
To assess the performance profiling technique within a larger sample size of ACL-injured patients, and to examined profiling technique within other symptomatic populations?
To assess the psychophysiological scaling of the profiling technique more longitudinally to further understand its psychophysiological relationship?
Examine the relationship of the knee extensors with patient-based outcomes??
Assess heterogeneity of waiting time from injury to surgery and control for the precise dose and volume of rehabilitation of patients?
END

APPENDIX 3

TABLE 72 - Search terms (in search strategy format) used in Medline and Embase electronic database search from 20th August 2013 to the 10th April 2014 [Key: mesh, medical subject heading; .mp, text heading; * Boolean search phase].

Column terms combined **with**	Patient/condition **AND**	Intervention **AND**	Comparative Intervention **AND**	Outcomes **AND**
OR	1. Knee/	31. Questionnaires/ or exp Self Report/	100. Objective Outcome Measure*.mp.	**NONE**
OR	2. Knee*.mp.	32. Self-Report*.mp.	101. Clinician Reported Outcome Measure*.mp.	
OR	3. Knee Joint/	33. Questionnaire*.mp.	102. Performance Based adj3 (Outcome* or	
OR	4. Knee Joint.mp.	34. (Self-Report* or Questionnaire*) adj5 (Anterior	Measure*).mp.	
OR	5. Knee Injuries/	Cruciate Ligament Or ACL).mp.	103. exp Exercise Test/	
OR	6. Knee Injuries.mp.	35. Psychological Tests/ or exp Psychometrics/	104. Exercise Test.mp.	
OR	7. Athletic Injuries/	36. Knee Rating Scale*	105. Functional Performance Test*.mp.	
OR	8. Athletic Injuries.mp.	37. Knee-Specific Instrument*	106. FPT.mp.	
OR	9. patient care/ or exp preoperative care/	38. (Subjective or Patient Reported or Patient	107. Human Activities/ or exp Physical Fitness/	
OR	10. Preoperative adj3 (Anterior Cruciate Ligament	Assessed) adj5 (Outcome Measure* or Outcome*	108. Physical Performance Test*.mp.	
OR	Reconstruction or ACL).mp.	or Instrument or Measurement).mp.	109. Physical examination/	
OR	11. Postoperative adj3 (Anterior Cruciate Ligament	39. P-BOM* adj5 (Anterior Cruciate Ligament or	110. Physical Exertion/	
OR	Reconstruction or ACL).mp.	ACL).mp.	111. Physical examination.mp.	
OR	12. Surger* adj5 (Anterior Cruciate Ligament or ACL).mp.	40. exp "Quality of Life"/	112. Diagnostic Test*.mp.	
OR	13. Ligaments, articular/ or exp anterior cruciate ligament/	41. Quality of Life.mp.	113. Functional Outcome* adj5 (Anterior Cruciate	
OR	or exp patellar ligament	42. QoL.mp.	Ligament or ACL).mp.	
OR	14. Anterior Cruciate Ligament/in, ph, su, tr [Injuries,	43. Sports Knee Scale.mp.	114. Functional Test* adj5 (Anterior Cruciate	
OR	Physiology, Surgery, Transplantation]	44. AAOS.mp.	Ligament or ACL).mp.	
OR	15. Anterior Cruciate Ligament.mp.	45. Activity Rating Scale.mp.	115. Muscle Strength Dynamometer/	
OR	16. ACL.mp.	46. Anterior Pain Questionnaire.mp.	116. Muscle Strength Dynamometer.mp.	
OR	17. ACL Deficient Knee.mp.	47. Cincinnati Knee Rating System.mp.	117. Dynamometry.mp.	
OR	18. ACL Deficiency.mp.	48. Cincinnati adj5 (Anterior Cruciate Ligament	118. Physical Examination/ or exp Muscle Strength/ or	
OR	19. Anterior Cruciate Ligament Replacement.mp.	Reconstruction or ACL)	exp "Range of Motion, Articular"/	
OR	20. reconstructive surgical procedures/ or anterior cruciate	49. Edinburgh Knee Function Scale*.mp.	119. Muscle Strength.mp.	
OR	ligament reconstruction/ Orthopaedic procedures/ or exp	50. EKFS.mp.	120. Range of Motion.mp.	
OR	anterior cruciate ligament reconstruction/	51. Functional Index Questionnaire.mp.	121. ROM.mp.	
OR	21. Transplantation, Autologous/	52. FIQ.mp.	122. Muscle Contraction/ or exp Isometric Contraction/	
OR	22. (Autograft* or Allograft*) adj5 (Anterior Cruciate	53. International Knee Documentation Committee	or exp Isotonic Contraction/ or exp Muscle	
OR	Ligament or ACL).mp.	Subjective Knee Form.mp.	Relaxation/	
OR	23. Bone-Patellar Tendon-Bone Graft/ph, rh [Physiology,	54. IKDC.mp.	123. Muscle Contraction*.mp.	
OR	Rehabilitation] Bone-Patellar Tendon-Bone Graft.mp.	55. Knee Injury and Osteoarthritis Outcome	124. Isometric Contraction*.mp.	
OR	24. Bone-Patellar Tendon-Bone.mp.	Score.mp.	125. Isotonic Contraction*.mp.	
OR	25. (Patellar Tendon or Hamstring Tendon) adj3 (Graft or	56. KOOS.mp.	126. Muscle relaxation*.mp.	
OR	Autograft*).mp.	57. Knee OA Severity Scale Knee.mp.	127. Isokinetic Muscle Test*.mp.	
OR	26. (Double-Bundle or Single-Bundle) adj5 (Anterior	58. Index of Severity for Knee Osteoarthritis	128. Isokinetic Strength Test*.mp.	
OR	Cruciate Ligament or ACL).mp.	59. ISK	129. exp Quadriceps Muscle/	
OR	27. Rehabilitation/	60. Knee Outcome Survey.mp.	130. lower extremity/ or exp knee/ or exp leg/ or exp	
OR	28. Rehabilitation.mp.	61. KOS.mp.	thigh/	
OR	29. (Rehab* or Rehabilitation) adj5 (Anterior Cruciate	62. Knee Outcome Survey-Activities Of Daily	131. (Quadricep* or Extensor*) adj3 (Strength or	
OR	Ligament or ACL).mp.	Living.mp.	Muscle).mp.	
OR	30. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12	63. KOS-ADL.mp.	132. (Hamstring* or Flexor*) adj3 (Strength or	
OR	or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or	64. Knee Pain Scale.mp.	Muscle).mp.	
OR	22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30	65. KPS.mp.	133. (Manual or Instru*) adj5 (Laxity Test*)	
OR		66. Knee Pain Screening Tool.mp.	134. Arthrometry.mp.	
OR		67. KNEST.mp.	135. Arthrometer.mp.	
OR		68. Knee Quality Of Life .mp.	136. KT-1000.mp.	
OR		69. KQol-26.mp.	137. KT-2000.mp.	
OR		70. Knee Self-Efficacy Scale.mp.	138. Knee Joint Laxity Test*.mp.	
OR		71. K-SES.mp.	139. Laxity Test* adj5 (Anterior Cruciate Ligament or	
OR		72. Knee Severity Scale.mp.	ACL or Knee).mp	
OR		73. Knee Visual Analog Scale.mp.	140. Anterior Drawer Test*.mp.	
OR		74. VAS adj5 (Anterior Cruciate Ligament or	141. Lachman Test*.mp.	
OR		ACL).mp.	142. electrodiagnosis/ or exp electromyography/	
OR		75. Kujala Anterior Knee Pain Scale.mp.	143. proprioception/ or exp kinesthesis/	
OR		76. Lower Extremity Activity Profile.mp.	144. Proprioception.mp.	
OR		77. LEAP.mp.	145. Sensorimotor adj5 (Performance or Test*).mp.	
OR		78. Lower Extremity Activity Scale.mp.	146. Pivot Shift*.mp.	
OR		79. LEAS.mp.	147. 6 Metre Walk Test*.mp.	
OR		80. Lysholm Knee Score.mp.	148. 6MWT.mp.	
OR		81. Marx Activity Rating Scale.mp.	149. Timed Up And Go Test*.mp.	
OR		82. Oxford Knee Score.mp.	150. TUG.mp.	
OR		83. OKS.mp.	151. Hop Test*.mp.	
OR		84. Pain Severity Scale.mp.	152. Single Leg Hop Test*.mp.	
OR		85. PSS.mp.	153. Single Legged Hop Test*.mp.	
OR		86. Quality Of Life Outcome Measure For ACL	154. One Leg Hop Test*.mp.	
OR		Deficiency.mp.		

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87. ACL-QOL.mp.
88. Short Form 36.mp.
89. SF-36.mp.
90. Sports Knee Rating Scale.mp.
91. Tegner Activity Scale.mp.
92. Visual Analogue Scale adj5 (Anterior Cruciate Ligament or ACL or Knee).mp.
93. Walking Impairment Questionnaire.mp.
94. WIQ.mp.
95. Western Ontario Meniscal Evaluation Tool
96. WOMET.mp.
97. Western Ontario and McMaster Universities Osteoarthritis Index.mp.
98. WOMAC.mp.
99. 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 or 51 or 52 or 53 or 54 or 55 or 56 or 57 or 58 or 59 or 60 or 61 or 62 or 63 or 64 or 65 or 66 or 67 or 68 or 69 or 70 or 71 or 72 or 73 or 74 or 75 or 76 or 77 or 78 or 79 or 80 or 81 or 82 or 83 or 84 or 85 or 86 or 87 or 88 or 89 or 90 or 91 or 92 or 93 or 94 or 95 or 96 or 97 or 98 or 99

155. One Legged Hop Test*.mp.
156. "range of motion, articular"/ or exp arthrometry, articular/
157. Thigh adj3 (Measure* or Circumference).mp.
158. Vertical Jump.mp.
159. Carioca.mp.
160. Tuck Jump.mp
161. Figure of Eight
162. 101 or 102 or 103 or 104 or 105 or 106 or 107 or 108 or 109 or 110 or 111 or 112 or 113 or 114 or 115 or 116 or 117 or 118 or 119 or 120 or 121 or 122 or 123 or 124 or 125 or 126 or 127 or 128 or 129 or 130 or 131 or 132 or 133 or 134 or 135 or 136 or 137 or 138 or 139 or 140 or 141 or 142 or 143 or 144 or 145 or 146 or 147 or 148 or 149 or 150 or 151 or 152 or 153 or 154 or 155 or 156 or 157 or 158 or 159 or 160 or 161 or 162
164. 31 AND 100 AND 163
165. randomi?ed controlled trial.pt.
166. controlled clinical trial.pt.
167. randomi?ed.ab.
168. placebo.ab.
169. clinical trials as topic.sh.
170. randomly.ab.

Column terms combined **with**	Patient/condition **AND**	Intervention **AND**	Comparative Intervention **AND**	Outcomes **AND**
OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR OR	1. Knee/ 2. Knee*.mp. 3. knee function/ or knee ligament injury/ or knee instability/ or knee injury/ or knee ligament/ or knee ligament surgery/ or knee cruciate ligament/ 4. Knee Joint.mp. 5. Knee Injuries.mp 6. Athletic Injuries.mp 7. Sport Injury/ 8. patient care.mp. or patient care/ 9. preoperative care.mp. or preoperative care/ Preoperative adj3 (Anterior Cruciate Ligament Reconstruction or ACL).mp. 10. Postoperative adj3 (Anterior Cruciate Ligament Reconstruction or ACL).mp. 11. Surger* adj5 (Anterior Cruciate Ligament or ACL).mp. 12. Ligaments.mp. or ligament/ 13. Anterior Cruciate Ligament.mp. or anterior cruciate ligament/ 14. anterior cruciate ligament rupture/ or anterior cruciate ligament/ or ligament surgery/ or ACL.mp. or anterior cruciate ligament reconstruction/ 15. ACL Deficient Knee.mp. 16. ACL Deficiency.mp. 17. anterior cruciate ligament rupture/ or Anterior Cruciate Ligament Replacement.mp. 18. Orthopedic Procedures.mp. or orthopedic surgery/ 19. Transplantation, Autologous.mp. or autotransplantation/ 20. (Autograft* or Allograft*) adj5 (Anterior Cruciate Ligament or ACL).mp. 21. tendon graft/ or Bone-Patellar Tendon-Bone Graft.mp. or bone patellar tendon bone graft/ or patella/ or tendon/ or bone graft/ or patella tendon/ 22. (Patellar Tendon or Hamstring Tendon) adj3 (Graft or Autograft*).mp. 23. (Double-Bundle or Single-Bundle) adj5 (Anterior Cruciate Ligament or ACL).mp. 24. rehabilitation/ or rehabilitation medicine/ or Rehabilitation.mp. or rehabilitation care/ or rehabilitation patient/ or athletic rehabilitation/ or rehabilitation research/ 25. (Rehab* or Rehabilitation) adj5 (Anterior Cruciate Ligament or ACL).mp. 26. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25	27. questionnaires.mp. or questionnaire/ 28. psychological aspect/ or exp self-report/ or self-evaluation/ or Self-Report*.mp. or rating scale/ 29. (Self-Report* or Questionnaire*) adj5 (Anterior Cruciate Ligament Or ACL).mp. 30. Psychological Tests.mp. or psychologic test/ 31. Knee Rating Scale*.mp. 32. scoring system/ or outcomes research/ or Knee-Specific Instrument*.mp. 33. (Subjective or Patient Reported or Patient Assessed) adj5 (Outcome Measure* or Outcome* or Instrument or Measurement).mp. 34. P-BOM* adj5 (Anterior Cruciate Ligament or ACL).mp. 35. Quality of Life.mp. or "quality of life"/ 36. QoL.mp. 37. Sports Knee Scale.mp. 38. AAOS.mp. 39. Activity Rating Scale.mp. 40. Anterior Pain Questionnaire.mp. 41. Cincinnati Knee Rating System.mp. 42. Cincinnati adj5 (Anterior Cruciate Ligament Reconstruction or ACL) 43. Edinburgh Knee Function Scale*.mp. 44. EKFS.mp. 45. Functional Index Questionnaire.mp. 46. FIQ.mp. 47. International Knee Documentation Committee Subjective Knee Form.mp. 48. IKDC.mp. 49. Knee Injury And Osteoarthritis Outcome Score.mp. 50. KOOS.mp. 51. Knee OA Severity Scale Knee.mp. 52. Index of Severity for Knee Osteoarthritis.mp. 53. ISK.mp 54. Knee Outcome Survey.mp. 55. KOS.mp. 56. Knee Outcome Survey-Activities Of Daily Living.mp. 57. KOS-ADL.mp. 58. Knee Pain Scale.mp. 59. KPS.mp. 60. Knee Pain Screening Tool.mp. 61. KNEST.mp. 62. Knee Quality Of Life .mp. 63. KQol-26.mp. 64. Knee Self-Efficacy Scale.mp. 65. K-SES.mp. 66. Knee Severity Scale.mp. 67. Knee Visual Analog Scale.mp. 68. VAS adj5 (Anterior Cruciate Ligament or ACL).mp. 69. Kujala Anterior Knee Pain Scale.mp. 70. Lower Extremity Activity Profile.mp. 71. LEAP.mp. 72. Lower Extremity Activity Scale.mp. 73. LEAS.mp. 74. Lysholm Knee Score.mp. 75. Marx Activity Rating Scale.mp. 76. Oxford Knee Score.mp. 77. OKS.mp. 78. Pain Severity Scale.mp. 79. PSS.mp. 80. Quality Of Life Outcome Measure For ACL Deficiency.mp. 81. ACL-QOL.mp. 82. Short Form 36.mp. 83. SF-36.mp. 84. Sports Knee Rating Scale.mp. 85. Tegner Activity Scale.mp.	95. Objective Outcome Measure*.mp. 96. Clinician Reported Outcome Measure*.mp. 97. Performance Based adj3 (Outcome* or Measure*).mp. 98. exercise test/ or excercise test.mp. 99. Functional Performance Test*.mp. 100. FPT.mp. 101. Physical Fitness.mp. or fitness/ 102. Physical Performance Test*.mp. 103. Physical examination/ 104. Physical Exertion/ 105. Physical examination.mp. 106. Diagnostic Test.mp. or diagnostic test/ 107. Functional Outcome* adj5 (Anterior Cruciate Ligament or ACL).mp. 108. Functional Test* adj5 (Anterior Cruciate Ligament or ACL).mp. 109. Muscle Strength Dynamometer/ 110. Muscle Strength Dynamometer.mp. 111. Dynamometry.mp. 112. Muscle Strength/ 113. measurement/ or Range of Motion.mp. or joint mobility/ or "range of motion"/ or "movement (physiology)"/ or joint/ or muscle strength/ 114. Muscle Strength.mp. 115. ROM.mp. 116. Muscle Contraction.mp. or muscle contraction/ 117. Isometric Contraction.mp. or muscle isometric contraction/ 118. Isotonic Contraction.mp. or muscle isotonic contraction/ 119. Muscle Contraction/ or exp Isometric Contraction/ or exp Isotonic Contraction/ or exp Muscle Relaxation.mp. or muscle relaxation/ 120. electromyography/ or muscle isometric contraction/ or isometrics/ or Isokinetic Muscle Test*.mp. or quadriceps femoris muscle/ or isokinetic exercise/ 121. isokinetic exercise/ or torque/ or muscle isometric contraction/ or isometrics/ or Isokinetic Strength Test.mp. or knee function/ 122. Quadriceps Muscle.mp. or quadriceps femoris muscle/ 123. hamstring muscle.mp. or hamstring/ 124. (Quadricep* or Extensor*) adj3 (Strength or Muscle).mp. 125. (Hamstring* or Flexor*) adj3 (Strength or Muscle).mp. 126. (Manual or Instru*) adj5 (Laxity Test*) 127. Arthrometry.mp. 128. Arthrometer.mp. 129. KT-1000.mp. 130. KT-2000.mp. 131. Knee Joint Laxity Test*.mp. 132. Laxity Test* adj5 (Anterior Cruciate Ligament or ACL or Knee).mp 133. Anterior Drawer Test*.mp. 134. Lachman Test*.mp. 135. electrodiagnosis.mp. or electrodiagnosis/ 136. electromyography.mp. or electromyography/ 137. proprioception.mp. or proprioception/ 138. Sensorimotor adj5 (Performance or Test*).mp. 139. Pivot Shift*.mp. 140. 6 Metre Walk Test*.mp. 141. 6MWT.mp. 142. Timed Up And Go Test*.mp. 143. TUG.mp.	**NONE**

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86. Visual Analogue Scale adj5 (Anterior Cruciate Ligament or ACL or Knee).mp.
87. Walking Impairment Questionnaire.mp.
88. WIQ.mp.
89. Western Ontario Meniscal Evaluation Tool
90. WOMET.mp.
91. clinical assessment tool/
92. Western Ontario and McMaster Universities Osteoarthritis Index.mp.
93. WOMAC.mp.
94. 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 or 51 or 52 or 53 or 54 or 55 or 56 or 57 or 58 or 59 or 60 or 61 or 62 or 63 or 64 or 65 or 66 or 67 or 68 or 69 or 70 or 71 or 72 or 73 or 74 or 75 or 76 or 77 or 78 or 79 or 80 or 81 or 82 or 83 or 84 or 85 or 86 or 87 or 88 or 89 or 90 or 91 or 92 or 93

144. Hop Test*.mp.
145. Single Leg Hop Test*.mp.
146. Single Legged Hop Test*.mp.
147. One Leg Hop Test*.mp.
148. One Legged Hop Test*.mp.
149. Thigh adj3 (Measure* or Circumference).mp.
150. Vertical Jump.mp.
151. Carioca.mp.
152. Tuck Jump.mp
153. Figure of Eight.mp.
154. 95 or 96 or 97 or 98 or 99 or 100 or 101 or 102 or 103 or 104 or 105 or 106 or 107 or 108 or 109 or 110 or 111 or 112 or 113 or 114 or 115 or 116 or 117 or 118 or 119 or 120 or 121 or 122 or 123 or 124 or 125 or 126 or 127 or 128 or 129 or 130 or 131 or 132 or 133 or 134 or 135 or 136 or 137 or 138 or 139 or 140 or 141 or 142 or 143 or 144 or 145 or 146 or 147 or 148 or 149 or 150 or 151 or 152 or 153

APPENDIX 4

Included studies (remaining 29) found following searches from Study 1 (Systematic review).

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs VS. C-BOMs		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Baltaci, Yilmaz, & Atay (2012). **Study**: Correlational study. **Location**: Turkey.	To compare the relationship between functional performance and muscle strength with ACL-reconstructed knees and age-matched healthy individuals acting as the control group.	**ACLR participants:** **n**=15: (15♂). **Age**: 29.6±5.9 years. **Height**: 176.4±8.3 cm. **Mass**: 77.7±10.3 kg. **Graft**: BPTB autograft (n = 15). **CONTROL*:** **n=15** (15♂). **Age**: 27.0±6.2 years. **Height**: 176.7±6.9 cm. **Mass**: 76.7±5.7 kg. ***15** males of similar age with no systematic disease (No significant differences between groups).	**HSS.** **Lysholm.** **Tegner.**	**Dynamometry** (Cybex6000, tested peak torque of flex. & ext. at 60° x 5 &180° x 10). **ROM.** **Ladder-hop-test**. **Vertical-jump-test.** **Slope-test.** **Stairs-test**. **Carioca.** **Side-run test.** **Figure-8 test.** **Shuttle-run-test 1.** **Shuttle-run-test 2.** **Triple-crossover-hop-test.** **Single-leg-triple-hop test.** **Single-leg-hop test.**	**Follow-up after surgery:** 20±3.1 months. Tegner activity scale measured pre- and post-operatively in ACL group. Correlation coefficient assessed by 'r_s' to evaluate relationships (Significance level set at $p<0.05$).	Lysholm/Single-leg-hop test. Lysholm/Single-leg-triple-hop-test. Lysholm/Triple-crossover-hop-test. Lysholm/Ladder-hop-test. Lysholm/Vertical-jump-test Lysholm/Shuttle-run-test 2. Lysholm/Stairs-test Tegner/Single-leg-hop test. Tegner/Single-leg-triple-hop test. Tegner/Triple-crossover-hop-test. Tegner/Ladder-hop-test. Tegner/Vertical-jump-test Tegner/Shuttle-run-test 2. Tegner/Stairs-test Tegner/Flex. Iso 180°/s ***p<0.05**	**0.56*** **0.55*** **0.66*** **0.62*** 0.08 0.02 0.25 0.13 0.08 0.28 0.37 0.15 **0.57*** 0.70 **0.52*** **=r_s**	Functional outcomes similar to those of healthy legs can be achieved following ACL reconstruction with BPTB grafting and rehabilitation. The similar functional test results of the operated and healthy subjects prove the effectiveness of the rehabilitation program.	**Considering the high number of objective tests presented, little correlational data was reported. The majority of relationship data compared objective and functional assessments only.** **Detailed descriptions and administration of all outcome measures were thoroughly reported.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs VS. C-BOMs		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Banff, Godfrey, Beard, & Breckenridge (1999). **Study:** Correlational study. **Location:** Australia.	To identify the most appropriate performance-based test assessing functional status of ACL reconstructed patients by examining the criterion validity, and the association between subjective and objective outcome measures commonly used in ACL assessment.	**ACLR participants:** **n**=50 **Age:** 23.7 (range: 18 - 49 years).	**Lysholm.** **IKDC.**	**KT-1000.** **Dynamometry.** **12m timed hop.** **Triple-cross hop test.** **Triple-hop for distance.** **Single-Leg Hop for distance.**	**Follow-up after surgery:** approximately 5-7 months Association between subjective versus objective outcome measures at 6-months post-surgery.	IKDC/12m timed hop IKDC/Triple cross over hop IKDC/Triple-hop distance IKDC/Single-hop distance Lysholm/12m timed hop Lysholm/Triple cross over hop Lysholm/Triple-hop distance Lysholm/Single-hop distance Lysholm/Dynamometry *** (p= <0.05)**	**0.742*** **0.517*** **0.508*** **0.494*** **0.58*** **0.404*** **0.376*** **0.390*** **0.48*** **= r**	Results suggested that the 12m-timed hop test was more closely associated with overall knee function, and may be the most appropriate clinical test to indicate whether a patient is able to safely return to sport.	**A supplement from Journal of Science and Medicine in Sport (conference proceeding)** **Limited demographic data for participants.** **Limited explanation of outcomes and methodology of the study, for example dynamometry characteristics not presented.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs VS. C-BOMs		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Borsa, Lephart, & Irrgang (1998). **Study:** Correlational study. **Location:** USA**.**	To determine if performance-based or patient-reported outcome measures of function are more effective in estimating disability in individuals with an ACL-deficient knee.	**ACLD participants:** **n=29:** (15♂:14♀). **Age**: 28.7±1.7 years (range: 18-50). Majority of ACL injuries were sports-related.	**Lysholm.** **Cincinnati (Mod.)**	**TDPM.** **SBI** (KAT2000). **Dynamometry** (Cybex-II)***** **EMG** (VM, VL muscles of tested limb). **One-leg hop test.** *** Tested at 60° flex. of MIC x 3 efforts).**	**Follow-up after injury:** 41.7±11.7 months (range, 2-228). **Randomisation**: TDPM randomised; SBI randomised for left & right feet.	Lysholm/One-leg hop Lysholm/SBI Lysholm/Dynamometry Lysholm/TDPM Cincinnati/One-leg hop Cincinnati/SBI Cincinnati/Dynamometry Cincinnati/TDPM	0.02 0.09 0.24 -0.19 -0.11 0.36 0.30 -0.34 **= r**	The findings from this study suggest that there were no significant relationships between subjective and objective outcome measures found. However, step-wise regression analysis revealed that two self-report measures that being the Cincinnati Knee Score and Lysholm Knee Score, as well as one performance-based outcome measure, the one-leg-hop test were the most effective estimates of disability.	**Limited descriptive demographic data for participants** **P values were not reported for correlations.** **Small sample size.** **No information reported on assessors.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs	OUTCOME MEASURES VS. C-BOMs	MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Bryant, Creaby, Newton, & Steele (2008a). **Study:** Cross-sectional correlational study. **Location:** Australia.	To examine the relationship between knee functionality (assessed by Cincinnati Knee Score) of ACLD and ACLR patients (with autologous BPBT and ST-GRA grafts) with hamstring antagonist torque generated during resisted knee extension throughout the operational range of the quadriceps muscles.	**ACLR participants:** Overall n=27 (27♂). **[Graft:** ST-GRA autograft (n = 13♂). **Age:** 22.9±3.8 years. **Height:** 176.6±5.1 cm. **Mass:** 79.4±7.3 kg. **Time from injury to surgery:** 14.2±4.5 months. BPTB autograft (n = 14♂) **Age:** 30.9±7.8 years. **Height:** 180.2±4.7 cm. **Mass:** 87.1±19.6 kg. **Time from injury to surgery:** 15.1±5.0 months]. **ACLD participants:** n=10 (10♂). **Age:** 30.7±8.6 years. **Height:** 176.2±5.0 cm. **Mass:** 72.4±4.8 kg. **Time from injury to assessment:** 75.6±72.5 months. Participants were included if aged between 18 to 35 years. The same exclusion criteria were applied in this study as in Bryant, Kelly and Hohmann (2008b).	**Cincinnati.**	**Dynamometry** (Cybex).[1,2] **Single-leg-hop.** **Timed-hop.** **Vertical hop.** **EMG.** [1] Two sets of 5 maximal knee flexion and extension repetitions at 180°/s. [2] Dynamometry assessing hamstring torque generated by the hamstrings muscle of each participant during 10 trials were averaged over 10° knee angular positions intervals corresponding to knee ROM between 80° knee flexion to the near terminal phase (10°) of knee flexion.	**Time from surgery to evaluation:** 14.2±4.5 months. **Time from injury to assessment for ACLD group:** 75.6±72.5 months. The same orthopaedic surgeon performed all surgeries and the subjective and objective evaluations. Participants for BPBT and ST-GRA grafts were matched on timing since reconstruction. For all hop tests, the non-injured limb was tested before the injured limb (each performed 3 times).	**Cincinnati versus Dynamometry [4]** Cincinnati/Flex 80°-70° Cincinnati/Flex 70°-60° Cincinnati/Flex 60°-50° Cincinnati/Flex 50°-40° Cincinnati/Flex 40°-30° Cincinnati/Flex 30°-20° Cincinnati/Flex 20°-10° Cincinnati/Flex 80°-70° Cincinnati/Flex 70°-60° Cincinnati/Flex 60°-50° Cincinnati/Flex 50°-40° Cincinnati/Flex 40°-30° Cincinnati/Flex 30°-20° Cincinnati/Flex 20°-10° Cincinnati/Flex 80°-70° Cincinnati/Flex 70°-60° Cincinnati/Flex 60°-50° Cincinnati/Flex 50°-40° Cincinnati/Flex 40°-30° Cincinnati/Flex 30°-20° Cincinnati/Flex 20°-10° *** p < 0.05**	**ACLD participants:** 0.230 (p=0.262) **0.588 (p=0.048)*** **0.657 (p=0.038)*** **0.784 (p=0.011)*** **0.741 (p=0.011)*** **0.702 (p=0.017)*** **0.802 (p=0.003)*** **BPTB participants:** **-0.580 (p=0.015)*** -0.394 (p=0.082) -0.367 (p=0.098) -0.279 (p=0.167) -0.188 (p=0.260) -0.061 (p=0.481) -0.089 (p=0.382) **ST-GRA participant** 0.388 (p=0.095) 0.377 (p=0.102) 0.429 (p=0.072) -0.010 (p=0.487) 0.006 (p=0.492) -0.110 (p=0.360) -0.257 (p=0.198) =r	Statistical analysis revealed moderate to strong positive correlations between hamstring antagonist activity at knee flexion intervals 70°-60°, 60°-50°, 50°-40°, 40°-30°, 30°-20°, and 20°-10° and knee functionality for the ACLD group. For the BPTB group, a significant moderate negative correlation was identified between the level of hamstring antagonist torque at 80°-70° knee flexion and knee functionality. No significant associations were found between hamstring antagonist torque across the range of knee flexion motion and knee functionality for the ST-GRA group.	**Female participants were excluded because of hormonal fluctuations which can limit studies external validity.** **No concomitant injuries present at surgery (exclusion criteria).** **Participants in ACLD and ACLR groups were not entirely homogenous.** **Participants with autologous BPTB grafts would have a slightly more rapid progression of rehabilitation than participants with ST-GRA.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES **P-BOMs VS. C-BOMs**	MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	<u>RESULTS</u> Correlations between subjective self-report and objective, functional, and performance based outcome measures	AUTHORS CONCLUSION	<u>COMMENTS</u>
Bryant, Kelly, & Hohmann (2008b). **Study:** Cross-sectional correlational investigation. **Location:** Australia.	To examine the relationships between knee functionality (Cincinnati) and neuromuscular characteristics of ACLR patients following surgery.	<u>**ACLR participants**</u>: n=13 (9♂:4♀). **Age:** 33.2±12.9 years. **Height:** 164.4±22.3 cm. **Mass:** 87.4±30.9 kg. **Graft**: BPTB autograft (n = 13). Participants were excluded if other concomitant ligament injuries were present bilaterally, or participants had had previous surgeries, an unstable knee, or were unable to regain full ROM. All participants must have had returned to sport at least 1-3 days per week. All ACL injuries were sports-related, whereby each participant performed their sport 4-7 times per week.	**Cincinnati.** **Dynamometry** (Biodex-3).[1] **Force Plate.**[2] **Vertical jump.** **Long-hop.** **Timed-hop,** [1] **[1]** Max. Iso. 3s + 6s duration at 30° flex. **[2]** 2 sets of Max. Ext. & Flex. at 180°.s-1). <u>**Analysis**</u>: [2] LLMS (Lower Limb Musculotendenous Stiffness) was assessed with involved and uninvolved limbs, whereby patients were instructed to hop on a force plate at a frequency of 2.2 Hz (metronome).	**Time from surgery to evaluation:** 6-9 months following surgery. All surgeries were performed by the same orthopaedic surgeon. Subjective measures completed prior to objective assessments. For all hop tests, the non-injured limb was tested before the injured limb (each performed 3 times).	Cincinnati/Dynamometry(VL)[3] **0.482 (p=0.018)** Cincinnati/Dynamometry(VM)[3] **0.670 (p=0.670)** Cincinnati/Ext. 80-70°[4] 0.402 (p=0.086) Cincinnati/Ext. 70-60°[4] **0.511 (p=0.037)** Cincinnati/Ext. 60-50°[4] **0.483 (p=0.047)** Cincinnati/Ext. 50-40°[4] **0.533 (p=0.030)** Cincinnati/Ext. 40-30°[4] **0.559 (p=0.023)** Cincinnati/Ext. 30-20°[4] **0.593 (p=0.016)** Cincinnati/Ext. 20-10°[4] 0.451 (p=0.061) Cincinnati/**LLMS** **-0.545 (p=0.041)** ***p<0.05** r = [3] Quadriceps Activation - a Limb Symmetry Index [LSI] was calculated for the EMG data by dividing the mean value of the involved limb by the mean of the non-involved limb and multiplying the result by 100. [4] Dynamometry assessing quadriceps strength, torque generated by quadriceps muscle of each participant during 10 trials were averaged over 10° knee angular positions intervals corresponding to knee ROM between 80° knee flexion to the near terminal phase (10°) of knee flexion.	Significant moderate, positive correlations were identified between knee functionality as assessed by the Cincinnati Knee Score and LSI calculated for quadriceps torques at 80°-70°, 60°-50°, 50°-40°, 40°-30°, and 30°-20° knee flexion. Similarly, statistical analysis revealed a significant moderate, negative correlation between knee functionality and lower limb musculotendinous stiffness normalised to body weight.	**Small sample size.** **No information reported on assessors.** **Sample size and power calculations were calculated to determine number of participants.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES **P-BOMs**	**VS. C-BOMs**	MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	**RESULTS** Correlations between subjective self-report and objective, functional, and performance based outcome measures	AUTHORS CONCLUSION	COMMENTS
Chia & Chok (1999). **Study:** Correlational study. **Location:** Singapore**.**	To examine the relationship between subjective reports (assessed by the IKDC) with clinicians based assessments specifically examining the association between ligamentous laxity (assessed by KT-1000) and ROM with patients following ACL reconstruction.	**ACLR participants:** **n**=21 (21♂). **Age**: 26.4 years (range: 16-38). **Graft:** ST-GRA autograft (n = 11) BPTB autograft (n = 7) Allografts (n = 3). Eighteen participants had ruptured their ACL only, with the remaining participants having concomitant injuries, such as a diagnosis of ACL rupture and meniscus tear (n = 2), ACL rupture and medial meniscus tear (n = 1), and ACL rupture with medial collateral ligament tear (n = 1).	IKDC.[1] [1] IKDC subsections: • Patients subjective assessment on **activity level**; • Patients subjective assessment on **symptoms** for pain, swelling and giving away; • And, functional test measured by one-leg-hop test.	ROM.[2] KT-1000.[3] One-leg-hop test. [2] measured with goniometer. [3] KT-1000 index was taken as the difference in KT-1000 values between the injured and non-injured limb.	**Time from surgery to study evaluation:** Both the objective and subjective outcome measures were assessed at 3 and 6 months post-surgery. Goniometry was performed by the same assessor on both testing occasions. Assessment of subjective and objective outcomes was evaluated by an independent examiner.	**Correlation at three months post-surgery:** IKDC (activity level)/KT-1000 0.026 IKDC (Symptoms)/KT-1000 **0.410** *[1] IKDC (functional)*/KT-1000 **0.515** *[2] IKDC (activity level)/ROM flex. 0.182 IKDC (Symptoms)/ROM flex. -0.082 IKDC (functional)*/ROM flex. **-0.404** *[1] IKDC (activity level)/ROM ext. -0.147 IKDC (Symptoms)/ROM ext. -0.076 IKDC (functional)*/ROM ext. **-0.417** *[1] **Correlation at six months post-surgery:** IKDC (activity level)/KT-1000 -0.031 IKDC (Symptoms)/KT-1000 -0.135 IKDC (functional)*/KT-1000 0.239 IKDC (activity level)/ROM flex. **-0.619** *[1] IKDC (Symptoms)/ROM flex. -0.167 IKDC (functional)*/ROM flex. -0.373 IKDC (activity level)/ROM ext. 0.180 IKDC (Symptoms)/ROM ext. -0.122 IKDC (functional)*/ROM ext. -0.102 *[1] p<0.01 = T *[2] p<0.05 *** One-leg hop test was conducted as part of the subsection 'functional tests' of the IKDC (P-BOM).**	The KT-1000 Index, ROM and IKDC scores were suggested as assessing different clinical aspects of participant's following ACL reconstruction surgery. Overall the study reported poor associations among the three outcome measures, as such, it was reported that the three different assessment tools are discrete entities and may be equally useful in measuring clinical outcome for patients undergoing ACL reconstruction surgery.	**Small sample size.** **Limited demographic data of participants presented.**

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Gleeson, Parfitt, Minshull, Bailey & Rees (2008). **Study:** Quantitative and experimental repeated measures design. **Location**: UK.	To assess the contemporaneous changes to estimates of psychophysiological fitness capability in individuals with unilateral ACL knee injury who have undergone reconstructive surgery and a subsequent early phase (2.5 months) of standardised physical rehabilitation conditioning.	**ACLR participants**: **n=9** (7♂:2♀). **Age**: 29.9 ±8.7 years (range: 16 - 44). **Graft:** BPTB autograft (n = 9). **Time from injury to surgery:** 20.4±13.2 months. **Male participants:** **Height**: 1.73 ± 0.07 m. **Weight**: 81.5 ± 5.8 kg. **Female participants**: **Height**: 1.65 m. **Weight**: 66.2±7.8 kg. Participants ranged from recreational, county, regional, and amateur to former national athletes.	**Performance Profile (PP).** [1] **IKDC.** **ERAIQ.** **POMS-BI.** [1] Performance profile technique using an individualised response to self-perceived **emotional** needs; the profile elicited by considering the question, 'Emotionally how have you been feeling since the injury?'	**Knee Laxity.** [2] **Dynamometry.** [3] **EMG.** [1] Knee laxity evaluated by custom-built equipment by measuring knee ligamentous compliance (**ATFD**). [2] **MVMA** was assessed on both knee flexors of the injured and non-injured limbs; neuromuscular indices of **PF**, **EMD** and **RFD** were calculated.	**Time from surgery to study evaluation:** Participants were assessed on <u>four</u> separate testing occasions **two weeks prior** to surgery, weeks **6, 8** and **10** post-surgery. Participants treated by the same consultant surgeon. Participants were randomly selected from a total of 50 patients. The physiotherapist and surgeon performed ROM and administered IKDC with ligament examination section. Measurement of knee laxity was randomised to both limbs.	**PRE-SURGERY** PP /ATFD $r_s = 0.68$ ($p < 0.05$) PP /PF $r_s = 0.85$ ($p < 0.01$) PP /EMD $r_s = -0.82$ ($p < 0.01$) **8-WKS. POST-SURGERY** ERAIQ[1]/ATFD $r_s = 0.79$ ($p < 0.05$) ERAIQ/PF $r_s = 0.75$ ($p < 0.05$) Performance Profile/ATFD $r_s = 0.72$ ($p < 0.05$) Performance Profile/PF $r_s = 0.82$ ($p < 0.01$) Performance Profile/EMD $r_s = -0.81$ ($p < 0.01$) Bi-POMS[2]/ATFD $r = 0.87$ ($p < 0.01$) Bi-POMS[3]/ATFD $r = -0.85$ ($p < 0.01$) Bi-POMS[3]/EMD $r = -0.77$ ($p < 0.05$) Bi-POMS[4]/PF $r = -0.72$ ($p < 0.05$) Bi-POMS[5]/ATFD $r = - 0.72$ ($p < 0.05$) Bi-POMS[6]/PF $r = 0.77$ ($p <0.05$) **10-WKS. POST-SURGERY** Performance Profile/ATFD $r_s = 0.70$ ($p < 0.05$) PP /EMD $r_s = -0.84$ ($p< 0.01$) ERAIQ (Pain)/ATFD $r = 0.78$ ($p < 0.05$) Bi-POMS[4]/PF $r = 0.74$ ($p < 0.05$) **[1] = ERAIQ sub section (discouraged)** **[2] = Bi-POMS sub section (tired-energetic)** **[3] = Bi-POMS sub section (depressed-elated)** **[4] = Bi-POMS sub section (confused-clearheaded)** **[5] = Bi-POMS sub section (hostile-agreeable)** **[6] = Bi-POMS sub section (anxious)**	Throughout a standardised rehabilitation programme of 10 weeks reported some strong significant positive and some negative correlations between subjective and objective forms of assessment.	**An exploratory and feasibility study examining the first attempt to assess the performance profile in a clinical setting.** **Small sample size.** **Excellent participation & compliance to the rehabilitation (assessed by physiotherapists and self-report diaries).** **Performance profiling was only measured up to 10 weeks post-surgery, thus, long-term effects of surgery and rehabilitation on perceived performance capabilities are not known.** **Non-significant correlational data was not reported.**

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Goh & Boyle (1997). **Study:** Correlational investigation. **Location:** Australia.	To examine the relationship between knee rating scales (Tegner, Noyes, and an analogue scale measuring overall knee function satisfaction) with four single-limb functional tests (6m and 12m timed hops, cross-over hop and stairs hopple) to determine correlations between these subjective knee scores and functional performance-based outcome measures.	**ACLR participants**: **n=**20 (15♂:5♀). **Age:** 28.0±3.7 (range: 20 - 34 years). **Graft**: BPTB autograft (n = 20). **Group 1**: Normal limb indices in all functional tasks. **Group 2**: At least one abnormal (≤85 score) **limb index.*** Participants who had undergone meniscal repairs or meniscectomy were included in this study, however, concomitant collateral ligament injuries to either limbs, or previous injury or surgeries to non-injured knee or significant post-operative complications were excluded.	**Tegner (Mod).** **Noyes (Mod).** **Analogue Scale** (overall knee satisfaction)**.**	**6m-timed hop.** **12m-timed hop.** **Cross-over hop.** **Stair Hopple.**	**Time from surgery to study evaluation:** All patients were examined two to four years post-surgery. Patients instructed not to participate in physical activity one day prior to testing. A standardised testing protocol was administered by the same assessor to all participants. The order of testing for functional hop tests was conducted in a random order. Each trial was performed three times per limb.	Noyes/6m-timed hop. Noyes/12m-timed hop. Noyes/Cross-over hop. Noyes/Stair Hopple. Analogue/6m-timed hop. Analogue/12m-timed hop. Analogue/Cross-over hop. Analogue/Stair Hopple. ***** ***Limb Index*** *was determined by assessing best performance scores of functional tests by calculating the uninjured limb performance divided by the operated limb for both timed hops, crossover-hop, and the stairs hopple tests (recorded as a percentages). For analysis, ACLR patients were sub-divided into two groups dependent on outcome performance, Group 1 were classified as normal if injured limb index was ≤ 85.*	**0.62 ($p < 0.05$)** **0.56 ($p < 0.05$)** 0.44 **0.75 ($p < 0.05$)** **0.72 ($p < 0.05$)** **0.57 ($p < 0.05$)** **0.50 ($p < 0.05$)** **0.69 ($p < 0.05$)** **= r**	Correlational analysis between subjective questionnaires and the functional hop tests reported fair to moderate correlations. However, a strong correlation was demonstrated between the 6m-timed hop and the analogue score assessing overall knee function satisfaction ($r= 0.72$, $p < 0.001$), and between the stairs hopple test and the Noyes questionnaire ($r = 0.75$, $p < 0.001$). To further analyse associations between the subjective questionnaires (Noyes and Analogue Scale) and the functional hop tests performed, the Limb Index was created for Group 1 and Group 2, normal and abnormal scores respectively. A step-wise multiple regression was reported, an r^2 value of 0.66 was reported for the relationship between Noyes and Limb Index, and a r^2 value of 0.76 for the relationship between limb indices and the analogue scale.	**A pilot test suggested that practicing the hop performance tests were required to achieve consistency of performance (ICC of 0.88), therefore a hop test familiarisation phase was conducted with all participants.** **The assessment of participants was carried out two to four years after surgery; however specific details were not reported.** **Leg dominance was assessed, as this may have affected outcome.** **Functional outcomes were randomised for each participant (method not reported).**

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Harilainen, Alaranta, Sandelin, & Vanhanen (1995). **Study:** Correlational study. **Location**: Finland.	To assess the relationships between muscle strength, severity of knee laxity and functional performance in chronic ACL deficiency prior to operative treatment.	**ACLD participants:** **n**=167 (98♂:69♀) **Age**: 28.7 (14.4-55 years).	**Lysholm.** **Tegner.**	**CA-4000.** [1] **Dynamometry** (Cybex-6000).[2] [1] Measured in **antereo-posterior (AP)** translation. [2] Concentric (isokinetic and isometric contractions) muscle strength was evaluated at **60°/s** and **180°/s** angular velocities (x 3 maximal peak torque efforts recorded for extensors and flexors).	**Follow-up after injury:** mean 2.7 years. If adequate muscle strength was evident (>75% of the non-injured limb) surgery was postponed until pre-rehabilitation was complete.	Tegner/AP laxity. Lysholm/AP laxity. Lysholm/Ext. Torque at 60°/sec. Lysholm/Iso.-Flexion.	0.1296 (NS) 0.0436 (NS) 0.1731 (p= 0.08) 0.2094 (p = 0.04) **r =**	No statistically significant differences were found between patients with good (>85%) or poor (< 85%) muscle strength with regard to knee laxity, Lysholm score or Tegner activity level at 60°/sec or 180°/sec angular velocities or isometric torques. However, only marginal correlations were observed between isokinetic extension (at 60°/sec velocity) muscle strength and Lysholm score. As a conclusion it seems that even a relatively good muscle performance does not compensate severe instability symptoms.	**Limited methodology and results sections reported.** **Non-significant correlational data was not reported.**

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Holm, Risberg, Aune, Tjomsland, & Steen (2000). **Study:** Prospective study of 151 patients with a two-year follow-up. **Location:** Norway.	To assess the relationship between subjective and objective outcome measures following ACL reconstruction surgery.	**ACLR participants:** **n**=151 (85♂:66♀) **Age:** 28±8.6 years (range: 15-62). **Graft**: BPTB autograft (n = 151). n=66<25 years (age: 20.1±3.5); n=85 ≥25 years (age 33.3±6.6) **Time from injury to surgery:** 27±49 months. Patients were excluded if participants were skeletally immature, had fractures or other major injuries to the lower extremity less than 12 months prior to surgery.	**Cincinnati.**	**Dynamometry.** [1] **Triple-jump.** [1] Muscle strength was tested isokinetically to both lower limbs at angular velocities of 60°/s and 240°/s. Performance variable measured was Total Work (TW). The percentage difference between the injured and non-injured limbs was calculated for analysis.	All subjective and objective examinations were performed **6**, **12**, and **24** months post-surgery. All patients were evaluated by the same two physical therapists recording the same tests in the same order at all the follow-up intervals. Dynamometry was performed on both limbs, with the non-injured limb tested first.	**6-Month post-surgery:** Cincinnati/TW. Ext. 60◦/sec Cincinnati/TW. Ext. 240◦/sec Cincinnati/TW. Flex. 60◦/sec Cincinnati/TW. Flex. 240◦/sec Cincinnati/Triple-jump **12-Month post-surgery:** Cincinnati/TW. Ext. 60◦/sec Cincinnati/TW. Ext. 240◦/sec Cincinnati/TW. Flex. 60◦/sec Cincinnati/TW. Flex. 240◦/sec Cincinnati/Triple-jump **24-Month post-surgery:** Cincinnati/TW. Ext. 60◦/sec Cincinnati/TW. Ext. 240◦/sec Cincinnati/TW. Flex. 60◦/sec Cincinnati/TW. Flex. 240◦/sec Cincinnati/Triple-jump	 0.34 0.32 0.31 0.11 0.31 0.39 0.19 0.17 0.06 0.27 0.34 0.16 0.28 0.15 0.34 **= r**	The correlations between the Cincinnati score and the other outcome measurements assessing muscle strength performance were low (r = 0.06 - 0.39). The highest correlations were found between the Cincinnati score and extension TW at 60◦/sec (r=0.34-0.39). The linear relationship between the muscle strength deficits and the Cincinnati score at the 2-year follow-up had a regression coefficient of r^2 = 0.11. The findings from this study suggest that the subjective assessment of knee function to some degree correspond to the muscle strength and the triple-jump tests, especially the knee extensor strength measured at low angular velocities (60◦/sec).	**Large sample size.** **High compliance of patients attending all subsequent testing sessions at week 6, 12 and 24 weeks post-surgery (143, 134 and 139 participants respectively).** **Both acute and chronic ACLR participants were examined together.** **No compliance to the** **rehabilitation programme was measured**

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Harter, Osternig, Singer, James, Larso, & Jones (1988). **Study:** Retrospective correlational investigation. **Location:** USA.	To identify specific knee stability and functional variables that were most predictive of patient's perceptions of knee function, with the purpose to examine the relationships between these subjective and objective variables following ACLR surgery.	**ACLR participants**: n=**51** (32♂:19♀) **Age**: 23.7 (range: 18-49 years) **Graft**: BPTB autograft (61%), STG autograft (39%). **Time from injury to surgery**: 22.1 months (range: 1 day to 16 years). All subjects possessed a normal contralateral knee for comparative purposes. Patients were all sport athletes injured during sports activities.	**KFR. POPF[1]. ARS. 10PT.** [1] POPF appears to be completed by orthopaedic surgeon at time of evaluation.	**KT-1000** (MEDmetric). **Dynamometry**(Cybex-11).[1] **RPerformance Profile** (Cybex-II Goniometer) **ACL.**[2] [1] Knee flexion and extension angular velocities measured at 120°/s. 'Maximal Torque' (**MT**) and 'Total Work' (**TW**) performance values were calculated. Isokinetic work capacity (endurance) was assessed by performance of 30 repetitions of knee extension and flexion at 180°/s. [2] ACI used to quantify the differences in anterior tibial displacement relative to the femur on instrumented Lachman tests employing externally applied loads of 68 N and 90 N with the knee in approximately 20° of flexion.	**Follow-up after surgery:** 48±20.9 (range: 24 - 101) months.	KFR/KT-1000 KFR/RPP KFR/ACI KFR/MT quad [1] KFR/MT ham [1] KFR/TW quads (180°/s) KFR/TW hams (180°/s) POPF/KT-1000 POPF/RPP POPF/ACI POPF/MT quad [1] POPF/MT ham [1] POPF/TW quads (180°/s) POPF/TW hams (180°/s) ARS/KT-1000 ARS/RPP ARS/ACI ARS/MT quad [1] ARS/MT ham [1] ARS/TW quads (180°/s) ARS/TW hams (180°/s) 10PT/KT-1000 10PT/RPP 10PT/ACI 10PT/MT quad [1] 10PT/MT ham [1] 10PT/TW quads (180°/s) 10PT/TW hams (180°/s) [1] = Measured at 120°/sec at 45° of flexion. .	-0.02 (p =0.45) 0.02 (p = 0.45) -0.05 (p = 0.36) 0.24 (p = 0.06) 0.11 (p = 0.23) 0.14 (p = 0.17) 0.12 (p = 0.21) **-0.31** (p = **0.01**)* 0.03 (p = 0.41) -0.16 (p = 0.13) 0.15 (p = 0.15) **0.38** (p = **0.005**)* **0.28** (p = **0.03**)* **0.33** (p = **0.01**)* -0.16 (p = 0.13) 0.03 (p = 0.41) -0.01 (p = 0.48) **0.24** (p = **0.05**)* **0.26** (p = **0.04**)* **0.31** (p = **0.02**)* 0.18 (p = 0.11) -0.12 (p = 0.21) 0.06 (p = 0.35) 0.06 (p = 0.34) 0.17 (p = 0.14) 0.07 (p = 0.33) 0.16 (p = 0.15) 0.12 (p = 0.22) r = ***(P < 0.05)**	The correlations among the isokinetic muscle performance variables were of the largest in magnitude (r > 0.80). With only one exception (KFR and 10PT, r > 0.62), the results of the correlational analyses revealed that none of the measures of knee stability and function accounted for more than 13% of the common variance with the patients' perceptions of postoperative knee function. Due to the lack of strong correlations between the total KFR score and the static/dynamic tests employed, additional correlational matrices for each KFR subscale (**Pain, Giving Way, Activity Level)** and the static and dynamic tests were computed in order to determine if a single factor, e.g., giving way, was directly related to one or more of the measures employed. None of the KFR subscales were highly correlated (r < 0.80) with selected static and dynamic tests employed in our study.	**No inferences were made regarding preoperative to postoperative improvement in knee stability or function.** **Activity Rating Scale (ARS) was developed for the study; therefore, has not been validated.** **Non-injured contralateral knee was used as a control.**

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Hrubesch, Rangger, Reichkendler, Sailer, Gloetzer, & Eibl (2000). **Study**: Correlational study. **Location**: Austria.	To examine the relationship between seven knees rating scales with the assessment of knee laxity measured by the KT-1000.	**ACLR participants:** **n=44** (26♂:18♀) **Age**: 33 (range: 17-57 years). **Graft**: BPTB autograft (n = 44). 17 athletes were injured in winter sports; 12 via ball sports; and 15 via non-sports related activities. **Time from injury to surgery:** 7.5 weeks.	**IKDC.** **Lysholm & Gillquist.** **Feagin & Blake.** **Cincinnati.** **Marshall.** **OAK.** **Zarins & Rowe.**	**KT-1000.**	**Time from surgery to assessment:** 19 (range: 9-36) months. At follow-ups occasions, a single examiner performed all tests. Subjective outcomes were completed following objective tests.	IKDC/KT-1000 Lysholm & Gillquist/KT-1000 Cincinnati/KT-1000 Marshall/KT-1000 OAK/KT-1000 Zarins & Rowe/KT-1000 Feagin & Blake/KT-1000	0.319 0.146 0.426 0.363 0.319 0.410 0.530 **= r_s**	The KT-1000 arthrometer measurements overall reported poor correlations with most of the subjective knee rating questionnaires, however, the KT-1000 correlated well with the IKDC form and the OAK knee score. Inadequate correlations were found between KT-1000 arthrometer measurements and the remaining knee rating scales.	**Limited demographic data of participants presented.** **Study focused mainly on inter-relationships between subjective questionnaires.** **Results not transparent; difficult to interpret.**

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Kannus (1988). **Study:** Correlational study. **Location**: Finland.	To examine the relationship between muscle performance parameters assessed by dynamometry with the subjective and functional outcomes of patients with ACLD knees.	<u>**ACLD participants:**</u> **n**=36 **Age:** 34 (range: 16-59) years. None of the patients had injured the contralateral limb (exclusion criteria).	**Lysholm.**	**Dynamometry** (Cybex-II).[1] [1] Isokinetic quadriceps and hamstring strength was measured at 60°/s and 180°/s. In addition, maximal isometric contractions were also performed at 60°. Peak Torque and Total Work (TW) was calculated.	**Time from injury to assessment:** 5.0±2.1 years. In every other participant, the uninjured limb was tested first, and in every other vice-versa to eliminate any learning effect.	Lysholm/PT (flexors)* **0.76*** **0.78*** Lysholm/PT (extensors)* **0.84*** **0.85*** Lysholm/TW (flexors)* **0.75*** **0.76*** Lysholm/TW (extensors)* **0.82*** **0.84*** *$p < 0.001$ = r = r_s * Correlation between mean relative PT and TW of knee flexors and extensors and Lysholm score.	The two measures of muscle performance parameters (peak torque & total work) were significantly positively correlated with the Lysholm knee score for both the knee extensors and the knee flexors; the nearer the muscle function of the ACL injured knee was that of the non-injured knee, the better the score.	**Chronic ACLD participants.** **Poor description of sample population, for example participant's gender.** **Limited description of the methodology and results sections**.

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			P-BOMs VS. C-BOMs					
Kocher, Steadman, Briggs, Sterett, & Hawkins (2004). **Study:** Correlational study (retrospective) **Location**: USA.	To examine the relationships between objective assessment of ligament stability and subjective assessment of symptoms and function following ACL reconstruction.	**ACLR participants:** **n**=202 (115♂:87♀) **Age**: 28.6 (range: 14.4-60) years. **Graft**: BPTB autograft (n = 177). ST-GRA autograft (n = 25) All participants were without concurrent meniscal or chondral injury and without contralateral ACL injury.	**Lysholm. Subjective variables** (Assessing symptoms.[1] Assessing function.[2]). **At follow-up:** [1] Pain, swelling, partial giving way, full giving way, locking, crepitus, stiffness, and limping. [2] Satisfaction with outcome, walking, squatting, ascending and descending stairs, running, cutting, jumping, twisting, activity limitation, sports level, ADL level, work level, knee function, and sports participation.	**KT-1000** (MEDmetric).[3] **Lachman.** **Pivot-shift.** [3] The manual maximal difference (**MMD**) of anterior tibial translation at 30° of flexion (comparing injured and non-injured limbs) and measured in mm.	**Follow-up after surgery:** 35.9 (range: 24-87) months. . Lachman & pivot-shift tests were conducted by either surgeon or sport medicine fellow (all had a 2 minimum years' experience). All examiners were blinded to instrumented knee laxity or pivot-shift results. In addition, patients were also blinded to the instrumented knee laxity, Lachman examination, and pivot-shift examination results.	Satisfaction/KT-1000 0.05 (p= 0.52) Sport level/KT-1000 -0.05 (p= 0.48) ADL level/KT-1000 -0.02 (p= 0.75) Work level/KT-1000 -0.01 (p= 0.99) Lysholm/KT-1000 -0.04 (p= 0.60) **= r_s*** * Correlation coefficient r_s values from the study were reported from text only, as such few relationships were reported. Relationships between subjective variables (symptoms and function) and Lachman and the Pivot-shift examinations were reported as Means (SD) or percentages.	KT-1000 arthrometer MMD and Lachman examination at follow-up had no significant (P>0.05) relationship with subjective outcome of **Symptoms** [1] and **Function** [2], and the Lysholm knee score. However, the pivot-shift examination had significant associations with certain Lysholm, subjective **symptoms** and **function** (*these included: partial and full giving away, functional deficits in cutting and twisting, satisfaction with outcome, activity limitation, overall knee function, sports participation*).	**KT-1000 values indicated normal distribution. However, pivot-shift examination was not presented.** **Inter-observer reliability for KT-1000 arthrometer MMD (n = 15 patients, between 3 assessors was assessed (ICC=0.83).** **13% of the total number of primary ACL patients were recruited, therefore, offers limited external validity.** **Multiple assessors may have compromised measurement precision, and masking potential relationships.**

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Kong, Yang, Ha, Jang, Seo & Kim (2012). **Study:** Matched-paired controlled correlational study. **Location:** Korea.	To assess the relationships between three functional performance tests (co-contraction, shuttle run and Carioca tests) with routine clinical outcome measures used in ACL reconstruction patients (and to assesses these with healthy participants acting as a control group).	**ACLR participants:** **n**=30 (30♂). **Age**: 23.43±3.17 years. **Height**: 177±7.07 cm. **Mass**: 77.07±8.41 kg. **Healthy participants:** **n=30** (30♂). **Age**: 24.73±2.16 years. **Height**: 174±4.58 cm. **Weight**: 74.95±10.75 kg. ACL group and healthy male subjects were matched for age, weight, height, and activity level (no significant differences between groups).	**Lysholm.** **IKDC.** **Tegner.**	**KT-2000.** **Dynamometry**(Biodex -III).[1] **One-leg hop.** **Co-contraction test.** **Shuttle run.** **Carioca test.** [1] Isokinetic tests were performed in both limbs at 60°/s for four times for knee extensors and flexors. **PT** and **TW** muscle performance variables were recorded.	**Follow-up after surgery:** ≥6 months post-operatively.	Lysholm/Co-contraction Lysholm/Shuttle run Lysholm/Carioca IKDC/Co-contraction IKDC/Shuttle run IKDC/Carioca Tegner/Co-contraction Tegner/Shuttle run Tegner/Carioca **[1] = p <0.01** **[2] = p <0.05**	-0.057 (p= 0.763) -0.191 (p= 0.320) -0.058 (p= 0.761) **-0.569 (p= 0.001)**[1] **-0.512 (p= 0.004)**[1] **-0.453 (p= 0.012)**[2] **-0.397 (p= 0.030)**[2] **-0.505 (p= 0.004)**[1] **-0.484 (p= 0.007)**[1]	In the ACLR group, the three functional tests (co-contraction, shuttle run and Carioca tests) were significantly correlated with the IKDC Score and Tegner Activity Score.	**The test-retest reliability for three functional performance tests was high, co-contraction (r=0.511, p=0.025), shuttle run (r=0.746, p=0.000), and carioca test (r=0.742, p=0.000).** **Study focused mainly on relationships between objectives functional tests (co-contraction, shuttle run and Carioca tests) versus dynamometry.**

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Lephart, Perrin, Fu, Gieck, McCue, & Irrgang (1992). **Study:** Correlational study. **Location:** USA.	To examine the relationship between traditionally used physical characteristics and functional capacity of individuals with an ACL insufficiency, and to compare functional results of two groups of ACL-deficient athletes (i.e. athletes able to return to competition and another group of athletes who cannot).	**ACLD participants:** **n**=41 (32♂:9♀) **Age**: 22.7 (range: 16-32) years. **Participants divided into two groups for additional analysis:** **(1)** Participants able to return to pre-injury level [n=29], and **(2)** participants unable to return to pre-injury level [n=12].	**IAKS**	**KT-1000** (MEDmetric). **Dynamometry** (Cybex-II).[1] **Thigh circumference.** **ROM.** **Carioca.** **Co-contraction.** **Shuttle-run.** [1] Isokinetic tests were performed in both limbs at 60°/s and 270°/s for six times for knee extensors and flexors. **PT**, **TAE** and reciprocal muscle ratios (**H:Q**) of muscle performance variables were calculated.	**Follow-up after injury:** 26.5 months All participants described as being in 'sub-acute injury stage' when follow-up was conducted. All participants testing occurred during a 1-week period. Day 1=objective tests, and day 2=subjective evaluations). .	IAKS/PT(flexors)(60°/s) 0.17 IAKS/PT(extensors)(60°/s) 0.15 IAKS/PT(flexors)(270°/s) 0.09 IAKS/PT(extensors)(270°/s) 0.13 IAKS/TAE(flexors)(60°/s) 0.24 IAKS/TAE(extensors)(60°/s) 0.26 IAKS/TAE(flexors)(270°/s) 0.22 IAKS/TAE(extensors)(270°/s) 0.23 IAKS/Q:H PT(60°/s) -0.04 IAKS/Q:H PT(270°/s) -0.10 IAKS/KT-1000 0.14 *** p<0.05** = r **Note:** Correlation coefficients for physical characteristics deficits and functional tests are not shown, reader referred to the study for details).	The study reports the lack of any strong correlation between the injured limb physical characteristics and the functional tests performed. The IAKS correlated well with the total functional performance tests (with an r value of -0.49).	**Limited demographic data of participants presented.** **Study focused mainly on relationships between objectives functional tests versus muscle performance assessed by dynamometry.** **Order of testing was randomised for both limbs.**

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Li, Maffulli, Hsu, & Chan (1996). **Study:** Intervention (pre and post design). **Location:** Hong Kong.	To examine the relationship between hamstring to quadriceps ratio (H:Q) and short-term functional outcome with athletes with ACL-deficient knees.	ACLD participants: n=46 (28♂:18♀) **Age:** ♂ 24.2±8.4 years ♀ 24.1±4.24 years. **Weight:** ♂ 64.8 ±9.2 kg. ♀ 54.5±5.5 kg. All participants were recreational athletes, and all were injured during sporting activities. All participants were required to not participate in additional exercise training programmes, or receive any addition physiotherapy.	**Cincinnati (modified).**[1] [1] **Cincinnati** questionnaire was completed prior to the strength intervention programme and completed again 6 weeks later.	**Dynamometry** (Cybex-II).[2] [2] Isokinetic tests were performed in both limbs at $30^{\circ -1}$ and $180^{\circ -1}$ knee extensors and flexors. PT, TW, END-R, and MP of muscle performance variables were calculated.	Isokinetic muscle training was performed three times a week for six weeks. After the 6-week period, dynamometry and Cincinnati was re-administered to all participants. Strength training programme was supervised by one of the research investigators.	Cincinnati/H:Q knee 30 Cincinnati/H:Q PKTAE Cincinnati/H 180 knee 30 Cincinnati/H 60 knee 30 Cincinnati/H:Q 180 PT Cincinnati/H 180 PT/BW Cincinnati/H 60 PT Cincinnati/H:Q W Cincinnati/H 60 PT/BW Cincinnati/H:Q 60 knee 30 Cincinnati/H:Q 180 PT Cincinnati/H PKTAE Cincinnati/H:Q 60 PT	**0.6249 (p <0.001)** **0.4721 (p <0.001)** **0.4646 (p <0.001)** **0.4479 (p <0.001)** **0.4383 (p <0.01)** **0.4240 (p <0.01)** **0.4134 (p <0.01)** **0.4099 (p <0.01)** **0.4026 (p <0.01)** **0.3752 (p <0.01)** **0.2685 (p <0.01)** **0.3531 (p <0.01)** **0.3436 (p <0.01)** **r =**		**The isokinetic training programme was aimed to strengthen the knee extensor and the knee flexor muscle group, and to establish a higher H;Q ratio on the injured limb. The training programme was individualised to each participant by adjusting a difference of 15% or less between the quadriceps strength; and an H:Q ratio of the injured knee approaching a score of 1.**

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Neeb, Aufdemkampe, Wagener, & Mastenbroek (1997). **Study**: Prospective observational design. **Location:** Netherlands.	To examine the relationship between self-report questionnaires with clinical and functional tests routinely used to evaluate the status of the ACL-reconstructed knee.	**ACLR participants:** **n**=30 (17♂:13♀). **Age**: 28.5±8.3 years. **Exclusion criteria**: **(1)** Diagnosed neurological disorders, **(2)** presence of orthopaedic-related problems, or (**3)** previous surgeries of the non-injured limb (*as this would hinder execution of the functional tests*). Concomitant injuries were also presented at time of surgery.	**SARS.** **FORSS.** **Lysholm.** **Tegner.**	**KT-1000.** **Lachman.** **Pivot-shift.** **One-leg-hop.** **Timed-hop.**	Prior to surgery, patients were assessed twice on each knee rating scale: to assess self-perceived status prior to the injury, to assess their post-injury status. Sequence of testing within categories (questionnaires, clinical tests, functional tests) was standardised. However, the order of testing of the categories was not standardised due to the availability researchers.	SARS/Pivot-shift FORSS/Pivot-shift Lysholm/Pivot-shift Tegner/Pivot-shift SARS/Lachman FORSS/Lachman Lysholm/Lachman Tegner/Lachman SARS/KT-1000 FORSS/ KT-1000 Lysholm/KT-1000 Tegner/KT-1000 SARS/One-leg-hop FORSS/One-leg-hop Lysholm/One-leg-hop Tegner/One-leg-hop SARS/Timed hop FORSS/Timed hop Lysholm/Timed hop Tegner/Timed hop	-0.07 0.16 -0.18 0.13 0.04 0.04 0.01 0.12 0.09 -0.19 -0.03 **0.25 ($p < 0.05$)** **0.24 ($p < 0.05$)** -0.01 0.12 0.21 **-0.22 ($p < 0.05$)** 0.05 -0.09 **-0.31 ($p < 0.05$)** = Ʈ	The study concluded that the levels of association between the questionnaires, clinical tests, and functional tests were poor.	**The inclusion of relevant outcome measures for use within the study were determined by a literature search.** **No randomisation of the sequence of tests within the testing categories between patients.** **There was no blinding of the assessors to whether patients had an ACL injury or not.** **Data concerning patients' performance after ACL reconstruction are not presented in this study.**

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Park, Kim, Yoo, Lee, Hwang, Chang, & Park (2010). **Study:** Retrospective **Location**: Korea.	To assess the relationships between dynamic postural stability, muscle strength, anterior instability, with knee rating scores with ACL-deficient knees.	**ACLD participants:** **n**=40 (40♂). **Age**: 27.0 ±7.2 (range: 18-44) years. **Height**: 71.1±6.28 cm. **Weight**: 73.15±11.7 kg. **BMI**: 25.37±2.63 Kg/m^2. Participants were excluded if concomitant injuries (meniscus lesions, multi-ligament or severe cartilage damage) to the knee were present, or having previous history of surgery.	**Lysholm.** **IKDC.**	**KT-2000** (MEDmetric). **Dynamometry** (Cybex-6000). [1] **BBS** [2] [1] Isokinetic parameters at angular velocities of 60°/s (4 times) and 180°/s (20 times) were measured and analysed. [2] Movement of the **BSS** platform was divided into 1 to 8 levels, most unstable condition to the most stable condition respectively. Stability Index (**SI**) would be calculated	**Time since injury to assessment:** 15±10 weeks. One assessor with one years' experience performed all arthrometry examinations to minimise errors.	Lysholm/BBS IKDC/BBS	**-0.49 (p = 0.001)** **-0.52 (p = 0.005)** **= r_s**	The study reported significant negative correlations between the Lysholm and the IKDC scores with dynamic postural stability that were moderately correlated.	**Limited results reported examining subjective and objective correlation coefficients.** **Only male patients were analysed, males and females would show very different demographic data and would incur a larger number of subjects to be analysed.** **Study focused mainly on inter-relationships between objective versus functional tests.**

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Risberg, Beynnon, Peura, & Uh (1999a). **Study:** Retrospective correlation investigation. Experimentally controlled with match-paired. **Location:** USA.	To examine the relationship between TDPM to other outcome measurements commonly used to evaluate the outcomes after ACL reconstruction (*KOOS, Cincinnati, one-leg hop test, stair hop test, and KT-1000 arthrometer test*)*****.	**<u>ACLR participants</u>**: n=20 (8♂:12♀). **Graft**: BPTB autograft (n = 20) **Age:** 35 (range 22-47) years. **Graft**: BPTB autograft (n = 20). All subjects had no previous injury or surgery to both knees. Nine patients had minor tears to the meniscus, of which five participants received partial meniscectomy. **<u>Healthy participants:</u>** n=10 (5♂:5♀). **Age:** 33 (range: 22-41) years.	**KOOS.[1] Cincinnati.** [1] KOOS sub-scales measured from 0-100 scale**.**	**KT-1000. TDPM.[1] One-leg hop Stairs hop.** [1] For all participants (ACL and healthy group) TDPM was evaluated with and without a brace conditions. Each participant had 12 trials in each condition.	**Time from surgery to follow up:** 24 (range: 11-32) months. Participants selected for TDPM were randomised. For ACL group, non-injured limb was always evaluated in an un-braced condition, as for healthy control group the braced leg was randomly selected to either left or right leg.	 KOOS-pain/TDPM KOOS-symptoms*/TDPM KOOS-ADL/TDPM KOOS-sport/TDPM KOOS-QoL/TDPM Cincinnati/TDPM	**ACLR limb** 0.21 0.17 0.09 0.14 0.33 0.21	**Non-injured limb** 0.34 0.22 0.17 0.27 0.32 0.34 = r	Moderate to low correlation coefficients were reported between TDPM and subjective self-report measurements (KOOS, Cincinnati, Tegner One-leg hop, Stairs hop, KT-1000).	**The reliability and accuracy of the TDPM equipment had been previously conducted.** **TDPM was randomised for each participant and leg condition (randomisation process not reported).**

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Reinke, Spindler, Lorring, Jones, Schmitz, Flanigan, Qi-An, Quiram, Preston, Martin, Schroeder, Parker, Kaeding, Borzi, Pedroza, Huston, Harrell, & Dunn (2011). **Study:** Quantitative experimental study. **Location**: USA.	To examine the relationships between four clinician-administered functional hop-tests and three patient-reported outcome measures correlated at a minimum of 2 years following ACL reconstruction surgery. **[Hypothesis:** hop-test scores would be more highly correlated with individual questions related to jumping than with the entire outcomes scores from the <u>overall</u> knee rating scale of that same questionnaire]	**<u>ACLR participants</u>:** **n= 69** (28♂:41♀) All participants were injured during sporting activities (*self-reported at the time of surgery*). All participants were required to be between the ages of 12 - 35, with no concomitant injuries greater than grade 2 sprains to the MCL, LCL or PCL	**KOOS.[1,2]** **IKDC.[1,2]** **Marx.[1,2]** [1] For the purpose of this study, examination of the relationships between the specific subsections of the KOOS and the IKDC questions were used, which related to jumping capability with the hop scores evaluated against this. [2] **<u>Calculating hop ratio</u>**: All hops performed increase with distance; therefore, hops were corrected for accrued learning effects.	**Single-hop.** **Triple-hop.** **Cross-over hop.** **6m-Timed-hop.**	**Time from surgery to follow up**: 2.2- 3.2 years (range: 26.4 - 38.4 months). Subjective evaluations were completed prior to objective hop-tests at the two-year follow-up appointments. Hop-tests were administered in the same order. All participants started with their right leg (regardless of their injured side) before repeating the process with their left leg.	IKDC/Single-hop IKDC/Triple-hop IKDC/Cross-over hop IKDC/Timed-hop KOOS[1]/Single-hop KOOS[1]/Triple-hop KOOS[1]/Cross-over hop KOOS[1]/Timed-hop KOOS[2]/Single-hop KOOS[2]/Triple-hop KOOS[2]/Cross-over hop KOOS[2]/Timed-hop MARX/Single-hop MARX/Triple-hop MARX/Cross-over hop MARX/Timed-hop [1] **KOOS - subsection - sport & recreation** [2] **KOOS - subsection - knee-related QoL**	**0.3 (p = 0.001)** **0.4 (p = < 0.001)** 0.2 (p = 0.23) **-0.3 (p = 0.03)** **0.2 (p = 0.05)** **0.2 (p = 0.05)** 0.2 (p = 0.07) -0.2 (p = 0.11) 0.2 (p = 0.19) **0.3 (p = 0.01)** 0.1 (p = 0.42) -0.2 (p = 0.08) 0.2 (p = 0.23) 0.2 (p = 0.17) -0.1 (p = 0.60) -0.2 (p = 0.14) **= r_s**	Using Spearman correlations between each self-reported outcome measure and each hop test ratio; the strongest relationship was reported to be a moderate, positive correlation between the IKDC scores and the hop ratios, particularly for the triple and single-hop tests. The KOOS Sports and Recreation sub-sections scores were weakly correlated with the triple and single-hop test. For the KOOS Knee Related Quality of Life subsection score, only the correlation with the triple-hop ratio was significant, and it had a moderate r_s value of 0.31. None of the hop ratios were significantly correlated with Marx activity levels.	**Limited demographic data for participants.** **Familiarisation phase of completing questionnaires at time of surgery.** **Study design attempted to control for extraneous variables in subject inclusion criteria.** **Multiple sites were not assessed for differences, however, this was minimised by conducing training sessions & site visits to standardise testing protocols.** **The number of failed hops attempted on each limb was recorded, this is the first time to asses this. Future research was suggested to further examine failed attempts in hop performance tests.**

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Risberg, Holm, Steen, & Beynnon (1999b). **Study:** Prospective observational design (with two year follow up). **Location**: Norway.	To examine the relationship between self-report questionnaires with objective outcomes to determine whether functional knee tests should be included and reported as a separate outcome measurement.	**ACLR participants:** **n**=120 (64♂:56♀). **Age**: 27.8 years (range: 14-50 years). **Graft**: BPTB autograft (n = 177). **The time from injury to surgery**: 27 (range 0-286) months. Participants excluded if concomitant PCL, MCL injuries present, or injury to contralateral limb.	**IKDC.**[1] **Cincinnati.** **Lysholm.** **Visual Analogue** (patient satisfaction). [1] Sub-divided into: Patient subjective assessment (**IKDC-1**), Symptoms (**IKDC-2**), ROM (**IKDC-3**), and Ligament examination (**IKDC-4**).	**KT-1000** (MEDmetrics). **Triple-jump.** **Stairs-hopple.** **ROM.**[2] [2] Goniometry: Goniometer used to calculate extension and flexion **deficits** (in degrees).	All participants were examined by the same assessor at 3 and 6 months, and at 1 and 2 years.	IKDC[3]/extension deficit (3 months) 0.83 IKDC[3]/extension deficit (6 months) 0.75 IKDC[3]/extension deficit (1 year) 0.77 IKDC[3]/extension deficit (2 years) 0.50 IKDC[3]/flexion (3 months) -0.70 IKDC[3]/flexion (6 months) -0.49 IKDC[3]/flexion (1 year) -0.37 IKDC[3]/flexion (2 year) -0.33 IKDC[4]/KT-1000 (3 month) 0.72 IKDC[4]/KT-1000 (6 month) 0.83 IKDC[4]/KT-1000 (1 year) 0.85 IKDC[4]/KT-1000 (2 year) 0.82 **= r_s** *IKDC[3] (ligament examination).* *IKDC[4] (compartmental findings).*	Authors concluded there was high criterion validity for IKDC[4] compared with the KT-1000 for all the follow-up times (range r_s = 0.72 - 0.85). IKDC[3] with flexion and extension deficit reported low validity at 3 months and 2 years after surgery, respectively.	**High compliance of patients attending all subsequent testing session at week 6, 12 and 24 weeks post-surgery**. **Study focused mainly on relationships between subjective self-report questionnaires.**

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Risberg, Holm, Tjomsland, Ljunggren, & Ekeland (1999c). **Study:** Single-group, repeated-measured prospective study. **Location:** Norway**.**	To assess the relationship between impairment measures (i.e. ROM, pain, knee-joint laxity, and muscle performance) and disability measures (Cincinnati, triple jump and stair-hop) commonly utilised in various intervals following ACL reconstruction.	**ACLR participants**: n=60 (32♂:28♀). **Graft**: BPTB autograft (n = 60) **Age:** 29.6±10.1 (range: 14-48) years. Low number of concomitant injuries present at time of surgery, 39% meniscus injuries, and 8% MCL. PCL ruptures were excluded. Majority of participants were injured during sporting activities.	**Cincinnati.**	**KT-1000** (MEDmetrics). **Dynamometry** (Cybex-6000).[1] **ROM.**[2] [1] Isokinetic tests were performed in both limbs at 60°/s[1] and 240°/s knee extensors and flexors. **TW** muscle performance variable was calculated. [2] Goniometry performed by the same assessor for all testing sessions.	**Time from injury to surgery:** 26±54.1 (range: 0-286 months). The same assessor evaluated all patients at testing occasions. All isokinetic testing performed by an independent assessor. The same testing procedure was performed in the same order of testing.	= r — **3 months** / **6 months** Cincinnati/ROM. Ext. -0.33 / -0.26 Cincinnati/ROM. Flex. 0.20 / 0.37 Cincinnati/Borg. Pain -0.64 / -0.47 Cincinnati/Ext. (60°/s) — / 0.29 Cincinnati/Ext. (240°/s) — / 0.44 Cincinnati/Flex. (60°/s) — / 0.31 Cincinnati/Flex. (240°/s) — / 0.18 Cincinnati/KT-1000 -0.13 / -0.01 = r — **1 year** / **2 years** Cincinnati/ROM. Ext. -0.08 / -0.08 Cincinnati/ROM. Flex. 0.23 / 0.05 Cincinnati/Borg. Pain -0.67 / -0.78 Cincinnati/Ext. (60°/s) 0.59 / 0.50 Cincinnati/Ext. (240°/s) 0.46 / 0.19 Cincinnati/Flex. (60°/s) 0.35 / 0.43 Cincinnati/Flex. (240°/s) 0.07 / -0.01 Cincinnati/KT-1000 0.03 / 0.09	The study reported that the Cincinnati knee score had significant relationships with pain, and more specifically with extension Total Work from 6 months to 2 years after surgery (r values from 0.29-0.59). The KT-1000 as a single impairment measurement had a poor correlation to the Cincinnati knee score at all follow-ups.	**The reliability and accuracy of dynamometry equipment had been previously conducted.** **Study focused mainly on relationships between objectives functional tests versus muscle performance assessed by dynamometry** **Uncontrolled compliance of rehabilitation following 3 months post-surgery**.

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Ross, Irrgang, Denegar, McCloy, & Unangst (2002). **Study:** Correlational study. **Location:** USA.	To examine the relationship between participation restriction in ADL and sport (*measured by KOS, SAS & ADLS*) following ACL reconstruction and the status of knee structure, performance based activity limitations (*i.e. single leg hop*), and impairments (*i.e. muscle performance and knee laxity tests*).	**ACLR participants**: **n**=50 (36♂:14♀). **Age:** 20.6±1.3 year. **Height:** 178±9.2 cm. **Weight:** 79.9±13.8 kg. **Graft**: ST-GRA autograft (n = 50). **Time from injury to surgery:** 32.2±28.8 (range: 10-154) days. All participants were air cadets (USA) Air Force Academy, considered physical fit. 96% of participants were injured during sports activities.	**KOS.**[1] **ADLS.**[1] **SAS.**[1] **Cincinnati. Knee Structure Assessment** (Struc. Inj.). [2] [1] Scores were combined to calculate and measure **'participation restriction'**. [2] Quantified by the number of structures in the knee that had been previously injured.	**KT-1000** (MEDmetrics). **Dynamometry.**[3] **Single-leg-hop.** [3] Isokinetic **PF** was tested at **60°/s** for the knee extensors only.	**Time from surgery to follow up:** 31.0±16.3 Subjective questionnaires were complete prior to objective and functional tests non-injured test first).	[KOS,ADLS,SAS]/Single-leg-hop 0.36 [KOS,ADLS,SAS]/PT(extensor) 0.29 [KOS,ADLS,SAS]/KT-1000 -0.01 [KOS,ADLS,SAS]/Time [4] 0.31 [KOS,ADLS,SAS]/Structures-Injured -0.70 **=r** [4] Time from ACLR surgery to testing of participants: 31.00±16.31 (range: 12-72) months. [5] Number of structures in the knee that had been previously injured each participant, not including the initial ACL injury.	A low correlation was found between combined scores from KOS, ADLS and SAS (i.e. participation restriction) to quadriceps peak torque index (r=0.29) and Single-Leg Hop for distance test (r=0.36). No correlation was reported between combined questionnaires score and side-to-side differences in anterior tibio-femoral joint laxity measured by the KT-1000 (r = -0.01).	**Test-retest reliability for KT-1000, Dynamometry, Single-Leg Hop for distance, and combined scores (of KOS, ADLS, SAS) (n = 10 patients, 5 days apart) was assessed, ICC values of 0.81, 0.95, 0.94 and 0.94 respectively).** **In comparing previously injured knee structures, the severity of the injury could not be accurately quantified.**

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Snyder-Mackler, Fitzgerald, Bartolozzi, & Ciccotti (1997). **Study:** Cross-sectional design. **Location:** USA.	To determine the relationship between the severity of passive joint laxity in relation to functional outcome following ACL injury. [**Hypothesis**: hypothesised that laxity measurements would not strongly correlate with functional ability].	<u>**ACLD participants:**</u> <u>Compensators (copers):</u> **n**=10; **Age**: 28.1 (16-47) years. <u>Non-compensators (non copers):</u> **n**=10; **Age:** 27.3 (22-27) years. Concomitant injuries to the injured & non-injured limbs were excluded. No difference in activity or frequency levels sports before ACLR surgery.	**Lysholm.** **KOS.** **IKDC.** **Global Knee Scale.**	**KT-2000** (MEDmetric).	**Participants in the non-copers group were evaluated at least 2 months post-injury, and copers groups were at least 6 months post-injury.** Two assessors performed all laxity measurements.	Lysholm/KT-2000 (at 89N) Lysholm/KT-2000 (manual. Max[4]) KOS(sports[1])/KT-2000 (at 89N) KOS(sports[1])/KT-2000 [4] KOS(ADL)[2]/KT-2000 (at 89N) KOS(ADL)[2]/KT-2000 (manual. max[4]) Global[3]/KT-2000 (at 89N) Global/[3]KT-2000 (manual. max[4]) [1.] **KOS (sport)**, the Knee Outcome Scale (KOS) sub-section score named 'sports' section. [2.] KOS **(ADL)**, the Knee Outcome Scale (ADL) sub-section score named 'Activates of Daily Living' section. [3.] Global, Global Knee Score. [4.] Manual**. Max**, measurement of anterior tibio-femoral laxity at manual maximum force.	0.005 0.033 0.052 0.078 -0.058 0.138 0.243 0.134	The correlations between knee laxity measurements using KT-2000 and functional knee ratings were reported as low and not significant.	**Small sample size.** **Authors stated from previous research that the inter-tester reliability of joint laxity measurements (KT-1000) were reported as being good.**

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Seto, Orofino, Morrissey, Medeiros, & Mason (1988). **Study:** Retrospective, correlational investigation with contralateral limb control. **Location:** USA.	To assess the following relationships at 5 years following ACL reconstruction: **(1)** Changes in muscular strength versus changes in knee ligament stability, **(2)** changes in muscular strength versus functional status, **(3)** changes in knee ligament stability versus functional status, and **(4)** the changes in pre-injury and follow-up patient participation levels for sports activities.	**ACLR participants**: n=25 (19♂:6♀) **Age:** 31.4±7.31 (range: 22 - 48) years. Extra-articular procedure: **n**=15 **Age**: 31.9±5.6 (range: 21-48) months. **Time from injury to surgery:** 272.5±305.7 (range: 4-884) months. Intra-articular procedure: **n**=10. **Age**: 30.8±5.0 (range: 24-38) months. **Time from injury to surgery:** 288.3±332.8 (range: 23-928) months. Knee injuries occurred during sports activity: non-contact (n = 13) and contact injuries (n = 10).	**FAS.**[1] **Sports Participation Survey.**[2] [1] The Functional Activity Scale (**FAS**) is comprised of both the **Lysholm and Gillquist**, and **Noyes** questionnaires. [2] Each participant completed a '**Sports Participation Survey**', as such, each participant indicated their activity level, pre-injury and present participation in sports levels by frequency and duration.	**Dynamometry** (Cybex-II).[3] **Lachman.** **Lateral-pivot shift.** **ROM.** **Ligament tests.** [3] **Four** maximal reciprocal knee flexion and extensions at 120 and 240°/s. [4] Ligament test performed bilaterally: Varus stress 0° extension, Varus stress 30° flexion, Valgus stress 0° extension, Valgus stress 30° flexion, Anterior draw (with tibia in neural rotation), and Anterior draw (with tibia in 15° external rotation).	**Time from surgery to follow up:** 5 years (4.84±14 years or 58.03±0.74 months) following ACLR [Extra-articular: 516.7 ± 322.9 (range: 212-1123) months, and. Intra-articular: 547±322 (range: 255-1198) months]. All objective tests were performed on the non-injured limb, except for the Lateral- pivot-shift. The subjects were instructed not to engage in any exercise on the day of testing. Each test conducted was assessed by separate assessors.	 FAS/Lachman FAS/Lateral-pivot FAS/Quad 240°/sec FAS/Quad 120°/sec FAS/Hams 240°/sec FAS/Hams 120°/sec FAS/Anterior drawer (neutral) FAS/Anterior drawer 15° external rotation FAS/Varus 0° ext. FAS/Varus 30° flex. FAS/Valgus 0° ext. FAS/Valgus 30° flex. **[1] (p < 0.01)** **[2] (p < 0.05)**	Extra-art -0.15963 -0.06407 0.5045 0.5031 -0.2875 -0.2700 -0.19625 0.12154 -0.36192 -0.36563 -0.10982 -0.26481 **= r**	Intra-art 0.18678 0.62532 **0.7916** [1] **0.7422** [2] **0.7456** [2] **0.7973** [1] 0.24689 0.39459 -0.14618 -0.14618 0.21797 0.22628 **= r**	No statistically significant correlations were found between FAS and the 8 stability tests for either the extra-articular or intra-articular group (P< 0.05). In addition, no statistically significant correlations were found between quadriceps and hamstring strength and the FAS of the extra-articular group. Positive correlations were found between the intra-articular group's FAS and quadriceps and hamstring strength parameters only.	**FAS was developed and tested in this study using aspects of the Lysholm and Noyes knee rating questionnaires.** **100 patients were initially contacted, 25 were recruited.** **Patients were excluded if concomitant injuries to the knee were present, or having previous knee surgeries to the non-juried limbs.** **To reduce risk of experimenter bias, each test conducted was assessed by a separate examiner.**

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Sernert, Kartus, Kohler, Stener, Larsson, Eriksson, & Karlsson (1999). **Study:** Prospective observational design (with two year follow up). **Location**: Sweden.	To assess the subjective and objective forms of assessments used following ACLR surgery and recovery to determine if correlations occur between these two types of evaluation methods.	<u>**ACLR participants:**</u> **n**=527 (349♂:178♀). **Age**: 26 (range: 14-51) years. **Graft**: BPTB autograft (n = 527). **Time from injury to surgery:** <u>median</u> 12 (1-360) months.	**Tegner.** **Lysholm.**[1] **IKDC.**[2] **Subjective Evaluation** **Subjective expectation** [1] Lysholm Knee Score has a '**Total**' score, and contains sub-sections for '**Pain**' and '**Instability**' scores. [2] **IKDC final classification** was used for analysis: IKDC graded as A (normal), B (nearly normal), C (abnormal), or D (severely abnormal). The final evaluation was calculated by the worst qualification within the subgroup determined the subgroup qualification and the worst subgroup qualification determined the final evaluation. [3] Patients **subjective evaluation** post-surgery was graded as 'Excellent', 'Good', 'Fair' or 'Poor'. [4] Patients **subjective expectations** post-surgery: Graded: Excellent, good, fair or poor.	**KT-1000** (MEDmetric). **ROM.** **One-hop-leg.** **Lachman.** **Donor-site-morbidity.** [5] **Loss of sensitivity** [3] Donor-site morbidity ('knee-walking-test') was evaluated using the kneeling and knee walking test; graded as normal, unpleasant, difficult or impossible to perform. [4] Loss of sensitivity ('knee sensitivity') was measured in square centimetres by the examiner by palpating the anterior knee region.	**Time from surgery to follow up:** median 38 (21-68) months. All participants were re-examined by an independent assessor who did not participate in the surgical procedure. The Tegner activity level was assessed by the examiner within a patient interview. ROM was conducted by a separate assessor.	Tegner/One-leg-hop 0.25 Tegner/KT-1000 (*total*) -0.06 Tegner/Lachman -0.06 Tegner/knee sensitivity -0.12 Tegner/KT-1000 (*anterior*) 0.06 Tegner/knee-walking-test 0.15 Lysholm (total)/One-leg-hop 0.36 Lysholm (Pain)/One-leg-hop 0.30 Lysholm (instability.)/One-leg-hop 0.28 Lysholm (total)/KT-1000 (*anterior*) -0.17 Lysholm (Pain)/KT-1000 *(anterior)* -0.12 Lysholm (instability)/KT-1000 *(anterior)* -0.21 Lysholm (total)/KT-1000 (*total*) -0.16 Lysholm (Pain)/KT-1000 (*total*) -0.11 Lysholm (instability)/KT-1000 (*total*) 0.20 Lysholm (total)/Lachman -0.26 Lysholm (Pain)/Lachman -0.19 Lysholm (instability)/Lachman -0.25 Lysholm (total)/knee sensitivity -0.22 Lysholm (Pain)/knee sensitivity -0.18 Lysholm (instability)/knee sensitivity -0.12 Lysholm (total)/knee-walking-test 0.41 Lysholm (Pain)/knee-walking-test 0.36 Lysholm (instability)/knee-walking-test 0.21 IKDC/One-leg-hop 0.28 IKDC/KT-1000 (*anterior*) -0.35 IKDC/Lachman -0.42 IKDC/KT-1000 (*total*) -0.34 IKDC/Donor-site 0.29 IKDC/knee sensitivity -0.14 Subj. evaluation/One-leg-hop 0.29 Subj. evaluation/KT-1000 *(anterior)* -0.18 Subj. evaluation/KT-1000 (*total*) -0.17 Subj. expectations/KT-1000 (*total*) -0.20 Subj. expectations/KT-1000 *(anterior)* -0.20 Subj. evaluation/Lachman -0.20 Subj. evaluation/knee-walking-test 0.39 Subj. evaluation/knee sensitivity -0.20 Subj. expectations/Lachman -0.19 Subj. expectations/knee-walking-test 0.26 Subj. expectations/One-leg-hop 0.20 Subj. expectations/knee sensitivity -0.08 = r_s	The IKDC evaluation system indicated a high correlation with the Lysholm (including the sub-scores), the KT-1000 tests, the manual Lachman examination, the patients' subjective evaluation and expectations, the Tegner activity level and the one-leg-hop test, indicating that the IKDC evaluation system appears to be a valid evaluation system after ACLR surgery. However, the laxity tests conducted reported no correlation with the subjective scores or the functional test.	**Large sample size in comparison to studies presented here in this table.** **A total of 95% (178♀; 349♂) returned for the follow-up examination at two years.** **All patients were re-examined by independent assessors.** **Results did not directly compare subjective and objective examinations; however, extrapolation of results could be easily identified.** **All evaluation systems reported no differences between participants with braces or no braces within the early stages of participants' rehabilitation programme.**

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Trulsson, Roos, Ageberg, & Garwicz (2010). **Study:** Correlational investigation utilising patients from larger RCT. **Location:** Sweden.	To assess the relationship between Tests for Substitution Patterns (TSP) scores with the subjective and objective outcome measurements following patients with ACL reconstruction surgery.	**<u>ACLR participants:</u>** n=53 (38♂; 15♀). **Age**: 30±5.2 (range: 20-39) years. **Graft**: BPTB autograft (n = 53). All ACL reconstructions were performed by a single surgeon. 54 participants were from an RCT of 121 subjects comparing the outcome of training and surgical reconstruction versus training only (one participant declined TSP, thus 53 subjects recruited).	**KOOS.**[1] [1] For this study, only the KOOS sub-sections scores for '**scale sport/rec**' were used; as these sections were relevant to the hop performance, muscle power, and postural orientation.	**TSP.** **Hop-leg hop.** **Weight Training machines.**[2] **Vertical-jump.**[3] **Side-hop.**[4] [2] Leg press of knee flexion tests at 110° to full extension, and 90° of the knee to full knee extension were performed respectively. [3] Measured by computer using an infrared light, measuring flight time and height of jump (cm). [4] Number of side hops on one leg within 30 seconds, over a distance 40 cm apart.	**Time from surgery to follow up:** 3.0±0.9 (range: 2-5) years. Right leg was tested first for each objective test. Dynamometry testing of muscle function was randomised. All tests conducted in a blinded manner	TSP/KOOS (Sport/rec).	- 0.43 ($p = 0.001$) = r_s	Moderate correlations were observed between TSP scores and KOOS sub-scale (sports/rec) scores ($r_s = -0.43$; $p = 0.001$) and between hop test (r_s =-0.40 to -0.46; $p \leq 0.003$), indicating that altered postural orientation was associated with worse self-reported KOOS sport/rec function and worse hop performance. No significant correlations were reported between TSP and muscle performance tests. Therefore, the authors conclude that the TSP is of patient relevance, and reflects specific aspects of neuromuscular control not qualified by other tests investigated.	**Double-blinded, cross-sectional study (i.e. assessor did not know any patient information, and both knees were covered with stocking to hide scars).** **Computerised leg press & knee flexion weight machines were used to calculate average power (W).** **Study focused mainly on relationships between TSP to objectives and functional tests.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs VS. C-BOMs		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures	AUTHORS CONCLUSION	COMMENTS
Tyler, McHugh, Gliem, & Nicholas (1999). **Study:** Cross-sectional design (one-year follow-up). **Location**: USA.	To examine the association between measurements of knee laxity using the KT-1000 arthrometer at 89 N and other subjective and objective outcome measures one year following ACL reconstruction.	**ACLR participants:** **n**=90 (46♂:44♀). **Age**: 31.0±8 years. **Graft**: BPTB-autograft (n = 90). Participants were divided, based on the amount of anterior-tibial displacement (*side-to-side difference*) based from KT-1000 assessment 1 year postoperatively: Categories were **tight**; **moderate**, and. **Loose.**	**Tegner. Lysholm. Subjective rating of instability.**	**KT-1000. Dynamometry. Pivot-shift. Lachman.**	**Time from surgery to follow up:** 13±3 months. KT-1000 testing was performed by two experienced assessors. Objective testing was completed prior to subjections questionnaires. Assessor was blinded to the results of the KT-1000 measurement.	Lysholm/KT-1000[1] -0.09 (p = 0.42) Tegner/KT-1000[1] 0.02 (p = 0.9) **= r** [1] = Side-to-side difference	Based on the reported results, it is evident that the side-to-side differences of the KT-1000 arthrometer measurements are not associated with other clinical measures of ACL instability at one year following ACLR surgery. Lysholm Knee Scores and Tegner Activity Levels were not associated with KT-1000 measurements (r values -0.09, p =0.42; r values = 0.002, p= 0.9 respectively). In addition, the relationships between the Lysholm and Tegner scores were not different between patients with 'tight' and 'loose' KT-1000 measurements (p = 0.39).	**All assessors were blinded to the results of the KT-1000 measurements, Lachman and Pivot-shift tests performed.** **All physical examinations were performed on bilateral knees by the same assessor (with 5 years' experience).**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES **P-BOMs VS. C-BOMs**		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Wilk, Romaniello, Soscia, Arrigo, & Andrews (1994). **Study:** Cross-sectional design **Location**: USA.	To examine the clinical outcome in terms of patients' self-assessment, dynamic strength, ROM, and three functional tests; to assess the relationships between these subjective and objective evaluation methods with patients with ACL-reconstructed knees.	**ACLR participants**: **n**= 50 (34♂:16♀) **Age**: 24.5 (range: 15-52) years. **Height**: 170 (range: 150- 198) cm. **Weight**: 75 (range: 53-109) kg. Forty-six patients were injured during sports activities, whilst the remaining four participants were injured during work or other activities.	**Noyes (Mod).[1] Overall knee function.[2]** [1,2] A subjective knee score questionnaire was modified from Noyes, Barber and Mooar (1989). The modified Noyes questionnaires also considered an overall knee function on an analogue scale 0 to 100 (*100 points represents a perfect knee*).	**Dynanometry** (Biodex).[3] **One-leg hop.*** **Single-leg timed hop.*** **6m-Single-leg cross over triple for distance.*** * For each functional hop, limb symmetry was calculated (for example, the mean score of the injured limb divided by the mean (or time) of the non-injured limb, and result multiplied by 100). [3] All participants were tested isokinetically at angular velocities of **180°/s**, **300°/s** and **450°/s** for both knee flexors and extensors. **PT**, acceleration (**A**) and decelerations (**D**) values were calculated.	**Time from surgery to testing**: 25.98 weeks (range: 21-30) weeks. All patients had at least two prior familiarisation sessions with the Biodex isokinetic dynamometer to ensure mastery of the apparatus and testing procedure. One assessor performed all isokinetic and functional examinations to exclude any potential examiner-related variability.	Noyes/ Ext. PT at 180°/s Noyes/ Ext. PT at 300°/s Noyes/ Ext. PT at 450°/s Noyes/ Flex. PT at 180°/s Noyes/ Flex. PT at 300°/s Noyes/ Flex. PT 450°/s Noyes/ Ext. A at 180°/s Noyes/ Ext. A at 300°/s Noyes/ Ext. A at 450°/s Noyes/ Ext. D at 180°/s Noyes/ Ext. D at 300°/s Noyes/ Ext. D at 450°/s Noyes/ Flex. A at 180°/s Noyes/ Flex. A at 300°/s Noyes/ Flex. A at 450°/s Noyes/ Flex. D at 180°/s Noyes/ Flex. D at 300°/s Noyes/ Flex. D at 450°/s Noyes/hop timed Noyes/cross-over hop Noyes/ Single-leg distance	**0.71 (p= 0.01)** **0.67 (p= 0.050**) 0.44 (p= 0.13) 0.18 (p= 0.251) 0.27 (p= 0.297) 0.39 (p= 0.212) **0.67 (p= 0.001)** **0.59 (p= 0.001)** 0.16 (p= 0.31) 0.27 (p= 0.12) 0.18 (p= 0.15) 0.15 (p= 0.22) 0.32 (p= 0.02) 0.26 (p= 0.09) 0.003 (p= 0.99) 0.16 (p= 0.24) 0.08 (p= 0.54) 0.03 (p= 0.84 **0.31 (p= 0.05)** **0.38 (p= 0.05)** 0.48 (p= 0.03) **= r**	There was a positive correlation between the modified Noyes questionnaire and the isokinetic dynamometry performance assessing the knee extensors 'peak torque' and 'acceleration phase' at both angular velocities of 180°/sec and 300°/sec. In addition, there appeared to be a significant relationship between the Noyes knee scores and the entire three hop tests performed, although only exhibiting a fair correlation value (ranging from 0.31 to 0.48).	**Fifty participants were randomly selected (randomisation procedures not reported).** **Isokinetic dynamometry was previously conducted twice to familiarise all participants.**

AUTHOR(S) / YEAR / STUDY TYPE	AIM & PURPOSE	POPULATION DEMOGRAPHICS	OUTCOME MEASURES P-BOMs VS. C-BOMs		MEASUREMENT SCHEDULE / ASSESSOR(S) / STATISTICS	RESULTS Correlations between subjective self-report and objective, functional, and performance based outcome measures		AUTHORS CONCLUSION	COMMENTS
Yates, AlKitani, Darain, Bailey and Gleeson (2016). [under review]. **Study:** Quantitative and experimental repeated measures design. **Location**: UK.	To assess the current changes to estimates of psychophysiological fitness capabilities in individuals with a unilateral ACL knee-injury who have undergone reconstructive surgery and a subsequent early phase (2.5 months) of standardised physical rehabilitation conditioning.	**ACLR participants:** **n=9** (5♂, 4♀). **Age**: 31.3 ± 9.7 (range: 18-46) years. **Graft:** BPTB autograft (n = 9). **Time from injury to surgery:** 23.4 ± 18.9 months Male participants: **Height**: 1.74 ± 0.08 m. **Weight**: 83.8 ± 6.0 kg. Female participants: **Height**: 1.62 ± 0.02 m. **Weight**: 64.0 ± 9.6 kg. Participants ranged from recreational, county, regional, and amateur to former national athletes.	**Performance Profile .[1] IKDC.** [1] Performance profile using an individualised response to self-perceived **physical** needs; the profile was elicited by considering the question: "What, in your opinion, are the elements of your knee in need of rehabilitation or improvement to obtain full recovery?"	**Knee Laxity.[2] Dynamometry.[3] SMP-FE.[4]** [2] Knee laxity evaluated by commercial equipment by measuring knee **ATFD**. [3] **MVMA** was assessed on both knee flexors of the injured and non-injured limbs; neuromuscular indices of **PF**, **EMD** and **RFD** were calculated. [4] Assessed as the ability to scale volitional force precisely (measured by force error, **FE**) arising from a task that required the 'blinded' replication using the knee flexors of a target force (50 % of PF).	Participants were randomly selected. The physiotherapist and surgeon performed ROM and administered IKDC with ligament examination section. Participants were assessed on four separate testing occasions two weeks prior to surgery, 6, 8 and 10 weeks post-surgery. Measurement of knee laxity was randomised to both limbs.	PP/ATFD. PP/EMD. PP/RFD. PP/SMP-FE.	0.68 ($p < 0.05$) 0.80 ($p < 0.01$) 0.69 - 0.71 ($p < .05$) 0.70 ($p < 0.05$) **= r_s**	The results indicated no significant relationships between ATFD, EMD, RFD, & SMP-FE, IKDC and the performance profile at each of the 4 testing occasions. However, when PP discrepancy scores from the assessments at week 8 and 10 were correlated with antecedent scores from ATFD, EMD, PF, RFD and SMP-FE at weeks 6 and 8, respectively, some significant relationships ($r_s = 0.68 - 0.80$; $p < .05$) and moderate biological relevance were found.	**Small sample size.** **Excellent participation & compliance to the rehabilitation.** **Performance profiling was only assessed to 10 weeks post-surgery, thus, long-term effects of surgery and rehabilitation on perceived performance capabilities is not known.** **Correlation data from the study was reported from text, only significant relationships reported with p values.**

APPENDIX 5

TABLE 73 - Frequency of Patient-Based Outcome Measures (P-BOMs) found following Systematic Review searches (Study 1).

Patient-based outcome measure	**Frequency**	**Study authors**
Lysholm Knee Rating Scale **(Lysholm)**	13	Baltaci et al., 2012; Borsa et al., 1998; Harilainen et al., 1995; Hrubesch et al., 2000; Kannus, 1988; Kocher et al., ,2004; Kong et al., 2012; Neeb et al., 1997; Park et al., 2010; Risberg et al., 1999b; Sernert et al., 1999; Snyder-Mackler et al., 1997; Tyler et al., 1999.
International Knee Documentation Committee **(IKDC)** Evaluating Form [a1, a2, a3, a4, a5, a6]	10	Chia and Chok, 1999 [a1]; Gleeson et al., 2008 [a1]; Hrubesch et al., 2000 [a5]; Kong et al., 2012 [a3]; Park et al., 2010 [a1]; Reinke et al., 2011 [a6]; Risberg et al., 1999b [a1 & a2]; Sernert et al., 1999 [a4]; Snyder-Mackler et al., 1997 [a1]; Yates et al., 2016 [under review] [a1]**.**
Cincinnati Knee Rating Scale **(Cincinnati)**	10	Borsa et al., 1998 **[modified]**; Bryant et al., 2008a; Bryant et al., 2008b; Holm et al., 2000; Hrubesch et al., 2000; Li et al., 1996 **[modified]**; Risberg et al., 1999a; Risberg et al., 1999b; Risberg et al., 1999c; Ross et al., 2002.
Tegner Activity Scale **(Tegner)**	7	Baltaci et al., 2012; Goh and Boyle, 1997 [**modified**]; Harilainen et al., 1995; Kong et al., 2012; Neeb et al., 1997; Sernert et al., 1999; Tyler et al., 1999.
Knee injury and Osteoarthritis Outcome Score **(KOOS)** [b]	3	Reinke et al., 2011; Risberg et al., 1999a; Trulsson et al., 2010.
Noyes Knee Rating Scale **(Noyes)**	2	Goh and Boyle, 1997 **[modified]**; Wilk et al., 1994 **[modified].**

[Activities of Daily Living Scale **(ADLS)**; Knee Outcome Survey **(KOS)**; Sports Activity Survey **(SAS)**] [d]	1	Ross et al., 2002.
Activity Rating Scale **(ARS)** [e]	1	Harter et al., 1988.
Bipolar Profile of Mood States **(BI-POMS)** [f]	1	Gleeson et al., 2008.
Emotional Responses of Athletes to Injury Questionnaire **(ERAIQ)**	1	Gleeson et al., 2008.
Functional Activity Scale **(FAS)** [g]	1	Seto et al., 1988.
Feagin and Blake Knee Score **(Feagin and Blake)** [h]	1	Hrubesch et al., 2000.
Factor Occupational Rating System Scale **(FORSS)**	1	Neeb et al., 1999.
Hospital for Special Surgery **(HSS)** knee scale	1	Baltaci et al., 2012.
Iowa Athletic Knee Rating Scale **(IAKS)** [i]	1	Lephart et al., 1992.
Knee Function Rating Form **(KFR)** [j]	1	Harter et al., 1988.
Post-Operative Physical Finding **(POPF)** form [k]	1	Harter et al., 1988.
Knee Outcome Survey **(KOS)**	1	Snyder-Mackler et al., 1997.
Marshall Knee Scores **(Marshall)**	1	Hrubesch et al., 2000.
Marx activity level **(MARX)**	1	Reinke et al., 2011.
Orthopaedic Working Group Knee Score **(OAK)**	1	Hrubesch et al., 2000.
Zarins and Rowe Rating Scale (**Zarins and Rowe)**	1	Hrubesch et al., 2000.
Sports Activity Rating Scale **(SARS)**	1	Neeb et al., 1997.
Sports Participation Survey **(SPS)** [l]	1	Seto et al., 1988.
10-Point Knee Scale **(10-PT)** [m (NRS)]	1	Harter et al., 1988.
Knee function [n, (NRS)]	1	Goh and Boyle, 1997.
Global knee scale **(GKS)** [o (VAS)]	1	Snyder-Mackler et al., 1997.
Current knee satisfaction/function [p (VAS)]	1	Wilk et al., 1999.
subjective variables [q]	1	Kocher et al., 2004.
Subjective rating of knee instability [r, (unknown rating scale (i.e., VAS, NRS): not reported)]	1	Tyler et al., 1999.
Subjective Evaluation [s,]	1	Sernert et al., 1999.
Subjective Expectation [s,]	1	Sernert et al., 1999.
Performance profile [c]	2	Gleeson et al., 2008; Yates et al., 2016.

APPENDIX 6

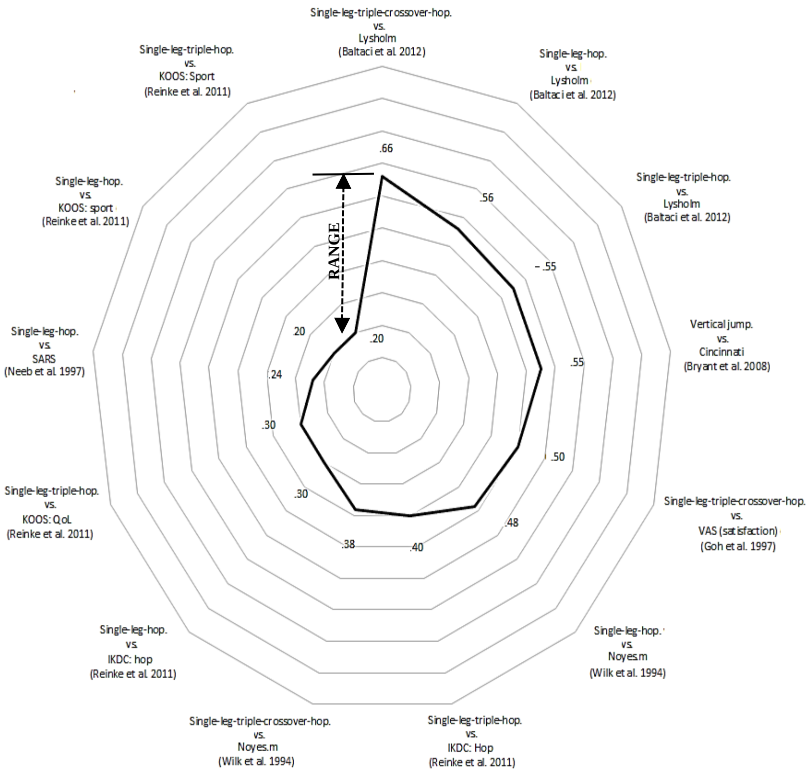
Individual result for all studies found (n = 30) following Systematic Review searches (Study 1).

P-BOMS VERSUS HOP-BASED PERFORMANCE TESTS/OUTCOMES

For this section, hop-based tests/outcomes found from 30 reviewed studies are divided into either distance or timed performances. Each reported correlation between C-BOMs (Hop: distance and time) versus P-BOMs are discussed separately.

HOP-BASED TESTS/OUTCOMES (ASSESSED BY DISTANCE).

Six studies (Baltaci et al., 2012; Bryant et al., 2008b; Goh et al., 1997; Wilk et al., 1994; Reinke et al., 2011; Neeb et al., 1997) reported evaluating hop-based tests/outcomes assessed by distances moved/hop on a single leg (single-leg-hop, single-leg-triple-hop, single-leg-crossover-hop, and vertical height jumped) versus P-BOMs using a combination of total and components scores (Lysholm, SARS, Cincinnati, MARX, FORSS, [KOS, ADLS, SAS], Tegner, Noyes (modified), IKDC, KOOS, and VAS) with ACLD and ACLR individuals.

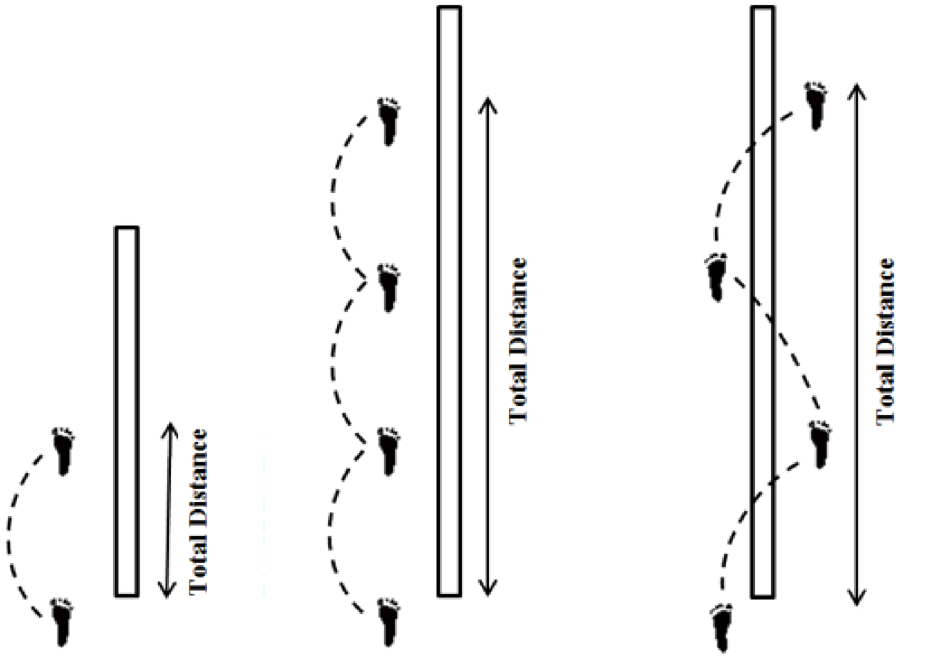


Significant correlations for P-BOMs versus jump performance outcomes (single-leg-hop; single-leg-triple-hop; single-leg-crossover-hop; vertical jump) tests evaluated by distance.

From these six studies, 42 correlations were reported when comparing hop-based tests/outcome for distance for all C-BOMS versus P-BOMs. From these 42 correlations, 13 correlation coefficient values were significant ($p< 0.05$). Each reported correlation between C-BOMs (Hop: distance) versus all P-BOMs are discussed separately.

P-BOMS VERSUS SINGLE-LEG-HOP-TEST FOR DISTANCE.

Seven studies reported using the single-leg-hop-test for distance versus a number of P-BOMs (Lysholm, SARS, Cincinnati, MARX, FORSS, [KOS, ADLS, SAS], Tegner, Noyes, KOOS, and VAS) (Baltaci et al., 2012; Borsa et al., 1998; Neeb et al., 1997; Sernert et al., 1999; Ross et al., 2002; Wilk et al., 1994; Reinke et al., 2011). The single-leg-hop test for distance is carried out by a participant standing on a single leg, who is then asked to jump forward as far as possible and then to land on the same leg. The distance covered by this leg is then recorded.



Schematic of all the single-leg-hop (single-leg-hop, single-leg-triple-hop, and single-leg-crossover-hop) tests/outcomes for distance (Source: Author's own diagram).

From these seven studies, 21 correlations were reported when comparing the single-leg-hop-test for distance with P-BOMS. From these 21 correlations, only five correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the single-leg-hop-tests for distance were, Lysholm ($r = 56$, $p < 0.05$, $n=15$); SARS ($\tau = 0.24$, $p < 0.05$, $n=30$); IKDC ('hop-test' subscale/component score, $rs = 0.30$, $p = 0.001$, $n=69$); KOOS ('sport and recreation' subscale/component score, $rs = 0.20$, $p < 0.05$, $n=69$), and the Noyes [modified] ($rs = 0.48$, $p = 0.03$, $n=50$).

In one study, the Lysholm was evaluated with the single-leg-hop-test for distance in ACLR patients. This study reported the highest correlation of all of the seven studies examining this P-BOM. A correlation coefficient value of $r = 0.56$ was reported ($p < 0.05$, $n=15$) (Baltaci et al., 2012); suggesting a positive moderate correlation between the Lysholm and the single-leg-hop-test for distance. When the Noyes (modified) was correlated with the single-leg-hop-test for distance in ACLR patients, the correlation coefficient was reported as, $rs = 0.48$ ($p = 0.03$, $n=50$) (Wilk et al., 1994); suggesting a positive low correlation. When the SARS was evaluated with the single-leg-hop-test for distance in ACLD individuals, a correlation coefficient value of $\tau = 0.24$ ($p < 0.05$, $n=30$) was reported (Neeb et al., 1997); suggesting a low positive correlation.

In one study, two correlations were reported in ACLR patients, correlating the IKDC ('hop-test' subscale/component score) and the KOOS ('sport and recreational' subscale/component score) with the Single-Leg Hop for distance-test for distance (Reinke et al., 2011). Here, the correlation coefficients were, $rs = 0.30$ ($p = 0.001$, $n=69$) and $rs = 0.20$ ($p < 0.05$, $n=69$), respectively. These results suggested a low correlation between the KOOS ('sport and recreation' subscale/component score) and the Single-Leg Hop for distance-test for distance, while a lower correlation was found between the IKDC ('hop-test' subscale/component score) and the single-leg-hop test for distance, suggesting no or a negligible correlation.

The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs and single-leg-hop-tests for distance. Correlational coefficients ranged from 0.20 to 0.56. Mean correlation coefficient values were calculated for individual coefficient statistics (τ = 0.24, rs= 0.28±.12, r = 0.56); suggesting that overall, there was a low to moderate correlation between P-BOMs and single-leg-hop-test for distance.

P-BOMS VERSUS SINGLE-LEG-TRIPLE-HOP TESTS FOR DISTANCE.

Three studies reported using the triple-jump test/outcome for distance versus a number of P-BOMs (Lysholm, Tegner, Cincinnati, IKDC, KOOS, and MARX) (Baltaci et al., 2012; Holm et al., 2000; Reinke et al., 2011). The single-leg-triple-hop-test for distance is carried out by a participant by standing on a single leg. The participant is asked to jump forwards on a particular leg three consecutive times as fast and as far as possible. The total distance is then measured and recorded. From these three studies, nine correlations were reported when comparing the single-leg-triple-hop-test for distance with P-BOMs. From these nine correlations, four correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the single-leg-triple-hop-test for distance were, Lysholm (rs= 0.55, $p < 0.05$, n=15); IKDC ('hop-test' subscale/component score, rs= 0.40, $p < 0.001$, n=69); KOOS ('sport and recreation' subscale/component score, rs= 0.20, $p < 0.05$, n=69), and the KOOS ('QoL' subscale/component score, rs= 0.30, $p < 0.01$, n=69).

The highest correlation coefficient value was reported when the Lysholm was compared with the single-leg-triple-hop-test for distance in ACLR patients (Baltaci et al., 2012). Within this study, the correlational coefficient value was rs= 0.55 ($p < 0.05$, n=15); suggesting a positive moderate correlation. In one study, four correlations were reported when assessing the relationship between three P-BOMs (IKDC, KOOS, and MARX) with the single-leg-triple-hop-test for distance (Reinke et al., 2011). Three of the four correlations were found to be significant [IKDC ('hop-test' subscale/component score, rs= 0.40, $p < 0.001$, n=69); KOOS ('sport and recreational' subscale/component score, rs= 0.20, $p < 0.05$, n=69); and KOOS ('QoL' subscale/component score, rs= 0.30, $p < 0.01$, n=69)].

Mean correlation coefficient values were calculated for all of the Spearman Ranking correlation coefficients (rs) statistics (rs= 0.40, rs= 0.20, rs= 0.30), therefore, a mean value of rs= 0.36 ± 0.15 [MEAN±SD] were found; suggesting that overall, there was a low to moderate correlation between P-BOMs and single-leg-triple-hop-test for distance. The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs (IKDC, KOOS, and MARX) with the single-leg-triple-hop-tests for distance. Correlational coefficients ranged from 0.20 to 0.55.

P-BOMS VERSUS SINGLE-LEG-TRIPLE-CROSSOVER-HOP TEST ASSESSED BY DISTANCE.

Four studies reported using the single-leg-triple-crossover-hop-test for distance versus a number of P-BOMs (Lysholm, Tegner, Noyes, VAS, IKDC, KOOS, and MARX) (Goh et al., 1997; Wilk et al., 1994; Reinke et al., 2011; Baltaci et al., 2012). The single-leg-triple-crossover-hop-test for distance is carried out by a participant standing on a single leg and hopping forwards over a distance of 6 metres (along painted stripe on the ground of 15 cm width) three times consecutively on the same leg. The total distance is then measured and recorded.

From these four studies, nine correlations were reported when comparing P-BOMs with triple-leg-crossover tests for distance. From these nine correlations, only three correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the single-leg-triple-crossover-hop-test for distance were the Lysholm (rs= 0.66, $p < 0.05$, n=15), overall knee satisfaction (r = 0.50 $p < 0.05$, n=20), and Noyes [modified] (r = 0.38, $p < 0.05$, n=69); suggesting the Noyes (modified) having a low positive correlation with the single-leg-triple-crossover-hop-test for distance. The Lysholm and the Knee Satisfaction P-BOMs are suggestive of a positive moderate correlation with the single-leg-triple-crossover-hop-test for distance.

The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs and single-leg-triple-hop-test for distance. Correlational coefficients ranged from 0.50 to 0.66. Mean correlation coefficient values (MEAN±SD) were calculated for individual coefficient statistics (rs= 0.66, r = 0.44 ± 0.06); suggesting that overall there was a low to moderate correlation between P-BOMs and single-leg-triple-hop-test for distance.

P-BOMS VERSUS VERTICAL-JUMP.

Two studies reported using vertical-jump tests versus a number of P-BOMs (Tegner, Lysholm, Cincinnati) (Baltaci at el., 2012; Bryant et al., 2008b). From these two studies, three correlations were reported when comparing P-BOMs with triple-leg-crossover tests for distance. Both studies used differing methodologies in vertical-jump tests. Firstly, Baltaci et al., (2012) asked participants to jump from a stationary stance, by bending knees and jumping vertically as high as possible. At this point the participant was also instructed to reach as high as possible with one arm. The total distance from the floor the highest point the participant reached was measured and recorded.

In the second vertical jump test conducted (Bryant et al., 2008b), the study's vertical jump test did not directly measure vertical distance as in the study conducted by Baltaci et al., (2012). However, a force plate was used to assess jumping performance. Here, participants were instructed to jump and hop on the both injured and non-injured limbs separately in time with a metronome at frequency of 2.2 Hz. Once a consistent hopping frequency was maintained for each limb; vertical ground reaction force data were recorded to assess lower limb musculotendinous stiffness (LLMS). In the first study (Baltaci at el., 2012), two correlations were reported in ACLR patients, correlating the Lysholm and the Tegner with the vertical-jump test for distance. Here, the correlation coefficients were rs= 0.08^{ns} and rs= 0.15^{ns}, respectively; suggesting no or negligible correlation with non-significant p-values reported.

In the second study (Bryant et al., 2008b), the Cincinnati was evaluated with the Lower Limb Musculotendinous Stiffness (LLMS) in ACLR patients. This study reported the only significant correlation with the LLMS, a correlation coefficient value of r = -0.55 was reported (p= 0.041, n=13); suggesting a negative moderate correlation between the Cincinnati and the vertical hopping performance task assessed by LLMS.

SUMMARY:

Four commonly-performed C-BOMs (single-leg-hop [n=21]; single-leg-triple-hop [n=9]; single-leg-crossover-hop [n=9]; vertical jump for distance [n=3]) evaluated by distance, were reported from the thirty included studies in this systematic review. In total, 15 studies evaluated jump performance capability for distance. From these 15 studies, 42 correlation coefficient values were reported. However, from these 42 correlations, only 13 correlation coefficient values were significant (p< 0.05). For all significant correlations found, and for all types statistics coefficients used in each study, a wide variety of correlations were found, ranging from 0.20 to 0.66 (single-leg-hop-hop (r = 0.56; τ= 0.24; rs= 0.20 - 0.48); single-leg-triple-hop (rs= 0.20 - 0.55); single-leg-crossover-hops for distance (r = 0.38 - 0.50; rs= 0.66).

ACLD:

Only one study (Neeb et al., 1997) was found evaluating SARS (P-BOM) versus single-leg-hop-test for distance with ACLD individuals (n = 30). This study reported none or very negligible correlation between SARS and single-leg-hop-test for distance (τ= 0.24; p< 0.05).

ACLR:

The majority of correlational relationships were found between a low to moderate relationship. The highest correlation coefficient values were found for Lysholm P-BOM versus all single-, triple- and crossover-hop-tests for distance in ACLR patients (r = 0.56, p< 0.05; rs= 0.55, p< 0.05, and rs= 0.66, p< 0.05 respectively).

The second highest correlation coefficient value were found for the Cincinnati outcome measures (r = 0.55, p= 0.04); suggesting a positive moderate relationship. The third highest correlation coefficient values were reported with the knee satisfaction ratings using the VAS with the single-leg-crossover hop test for distance (r = 0.50, p< 0.05, n=20), suggesting a positive moderate relationship. The difference with knee satisfaction outcome versus Lysholm and Cincinnati, is that patients would score perceived knee satisfaction from a 0 to 100 score, as opposed to a number of predetermined questions as recorded within the Lysholm/Cincinnati P-BOMs.

The fourth highest correlation coefficient values were reported when modified Noyes P-BOM versus single-leg-hop ($rs = 0.48$, $p = 0.03$, $n=50$) and single-leg-crossover hop tests for distance ($r = 0.38$, $p < 0.05$, $n=50$), suggesting a positive low to moderate relationships, respectively. The remaining P-BOMs (SARS, IKDC [hop-test subscale/component score], KOOS [sport subscale/component score], and KOOS [QoL subscale/component score]) were significantly correlated ($p < 0.05$) with C-BOMs, however, were all found to have a low positive correlation (all correlations ≤ 0.31).

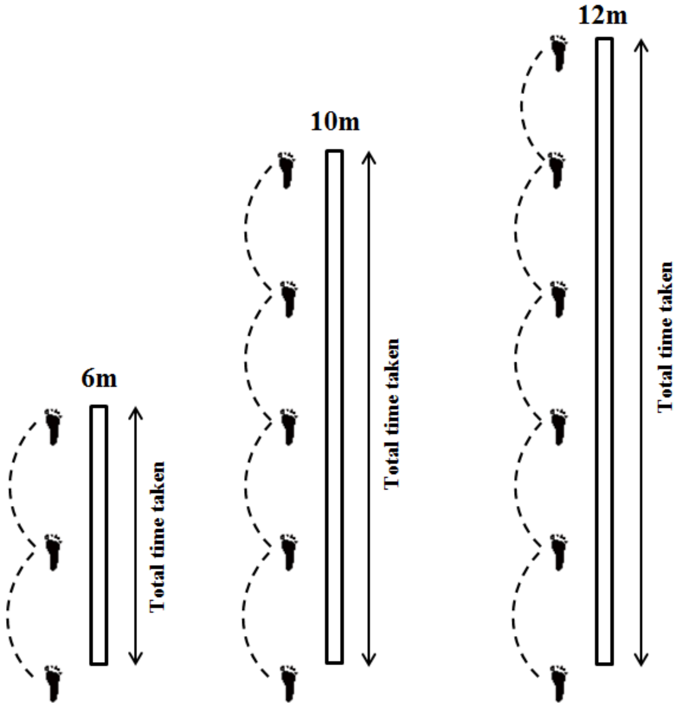
HOP-BASED TESTS/OUTCOMES (ASSESSED BY TIME).

Four studies (Goh et al., 1997; Reinke et al., 2011; Wilk et al., 1994; Neeb et al., 1997) reported evaluating hop-based tests/outcomes assessed with respect to time (Single-leg-hop tests performed at 6 m, 10 m and 12 m distances) versus P-BOMs using a combination of total and components scores (Lysholm, Tegner, VAS, IKDC, KOOS, MARX, Noyes, SARS, and FORSS) with ACLR individuals.

The timed-single-leg-hop for distance is carried out by a participant standing on a single leg, then participants are asked to jump forwards continuously for a measured distance (either 6 m, 10 m, or 12 m distances) on the same leg. The time to complete the designated distances would be measure in time and recorded.

From these six studies, 13 correlations were reported when comparing hop-based tests/outcome for time versus P-BOMs (as above). From these 13 correlations, 8 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (Hop: time) versus all P-BOMs are discussed separately.

All single-leg-hop tests/outcomes for timed distances (6 m, 10 m, and 12 m) are shown schematically in

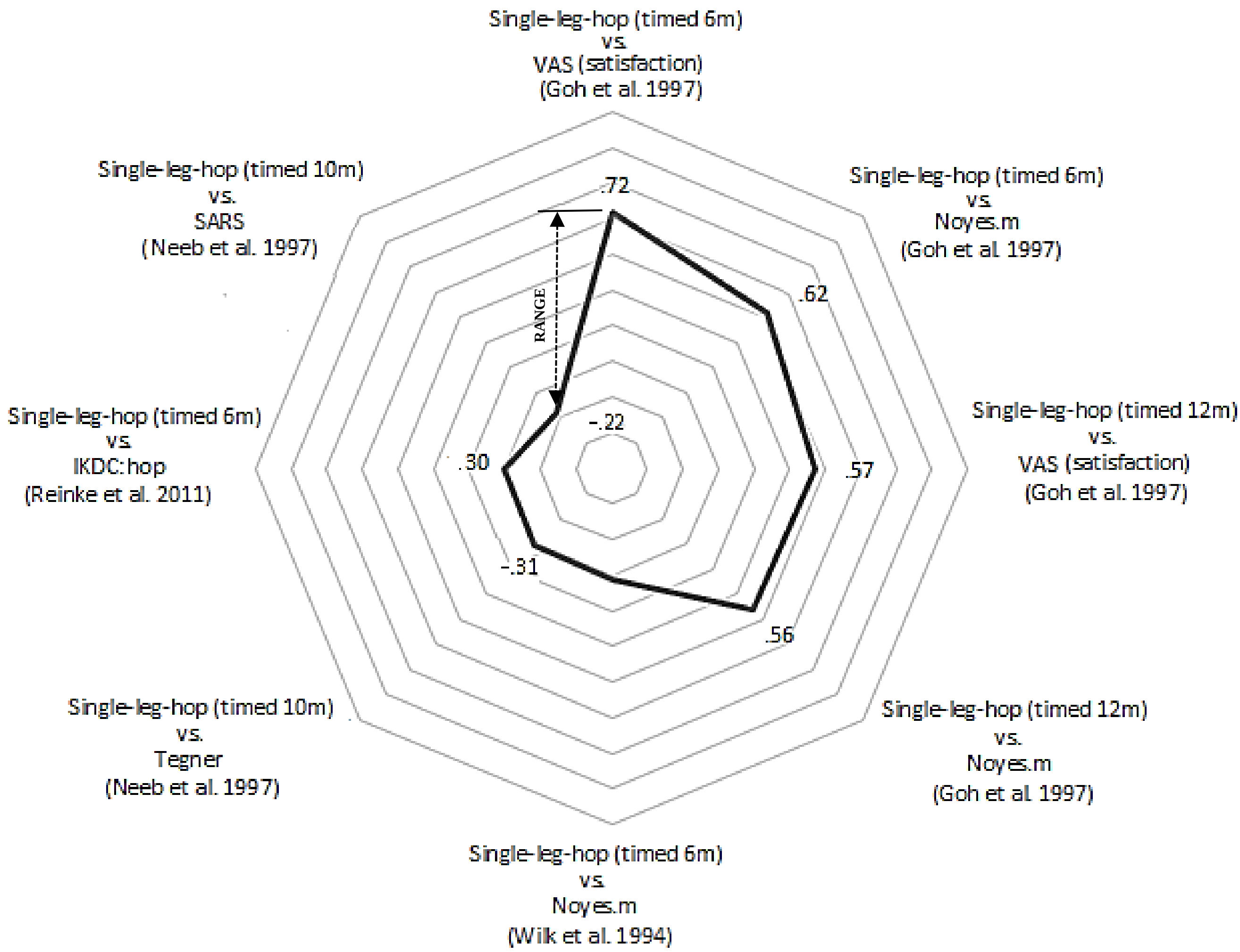


Schematic of all the timed-single-leg-hop tests evaluated by time (6 m, 10 m, 12 m distances) (Source: Author's own diagram).

P-BOMS VERSUS SINGLE-LEG-HOP (6 M DISTANCE) TEST/OUTCOME ASSESSED BY TIME.

Three studies reported using a timed single-leg-hop-test at a 6 m distance versus P-BOMs (Noyes modified, VAS, and IKDC) with ACLR individuals (Goh et al., 1997; Wilk et al., 1994; Reinke et al., 2011). From these three studies, 7 correlations were reported evaluating correlations between a timed single-leg-hop-test at 6 m distance versus P-BOMs. From these 7 correlations, 4 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (Hop: timed performance over 6 m distance) versus all P-BOMs are discussed separately.

In one study (Reinke et al., 2011), four correlations were reported assessing the relationship between three P-BOMs (IKDC, KOOS, and MARX) with the timed-single-leg-triple-hop-test at 6 m distance. Only one correlation from the four was found to be significant (IKDC: 'hop-test' subscale/component score, rs= -0.30, p= 0.03, n=69) suggesting a positive low correlation. Similarly, in the second study, Wilk et al., (1994) conducted the same timed-single-leg-hop-test at 6 m distance versus Noyes (modified), and correlation coefficient value of $r = 0.31$ ($p < 0.05$, n=50) was found, again suggesting a low correlation, but being positively correlated. In the last study (Goh et al., 1997) examined the Noyes (modified) and overall knee satisfaction assessed by VAS P-BOM with the timed-single-leg-hop-test at a 6m distance. Two correlations were found to be significant ($r = 0.62$, $p < 0.05$, n=20; $r = 0.72$, $p < 0.05$, n=20, respectively), suggesting moderate and high positive correlation for the timed-single-leg-hop-test at a 6 m distance versus Noyes (modified) and VAS (knee satisfaction), respectively.



Significant correlations for P-BOMs versus jump performance outcomes (single-leg-hop) tests evaluated by timed distances at 6 m, 10 m and 12 m.

P-BOMS VERSUS SINGLE-LEG-HOP (10M DISTANCE) TEST/OUTCOME ASSESSED BY TIME.

One study reported using a timed single-leg-hop-test at a 10 m distance versus P-BOMs (SARS; FORSS; Lysholm, and Tegner) with ACLR individuals (Neeb et al., 1997). From this one study, 4 correlations were reported evaluating correlations between a timed single-leg-hop-test at a 10 m distance versus P-BOMs. From these 4 correlations, 2 correlation coefficient values were significant ($p< 0.05$). Each reported correlation between C-BOMs (Hop: timed performance over 10 m distance) versus all P-BOMs are discussed separately. In the only study examined here (Neeb et al., 1997), two correlations from the four were found to be significant (SARS: $\tau= -0.22$, $p< 0.05$, n=30; Tegner: $\tau= -0.31$, $p< 0.05$, n=30); suggesting that overall, there was a low to no correlation between P-BOMs and timed-single-leg-hop-test at 10 m distance.

P-BOMS VERSUS SINGLE-LEG-HOP (12 M DISTANCE) TEST/OUTCOME ASSESSED BY TIME.

One study reported using a timed single-leg-hop-test at 12 m distance versus P-BOMs (VAS, modified Noyes) with ACLR individuals (Goh et al., 1997). From this one study, 2 correlations were reported evaluating correlations between a timed single-leg-hop-test at 12 m distance versus P-BOMs. From these 2 correlations, 2 correlation coefficient values were significant ($p< 0.05$). Each reported correlation between C-BOMs (Hop: timed performance over 12 m distance) versus the P-BOMs being discussed separately. In this study, two correlations were found to be significant (Noyes modified: $r = 0.56$, $p< 0.05$, n=20; VAS: $r = 0.57$, $p< 0.05$, n=20); suggesting that overall, there was a moderate positive correlation between P-BOMs and timed-single-leg-hop-test at 12 m distance.

SUMMARY.

Four studies reported to evaluate hop-based tests/outcomes performed at 6 m, 10 m and 12 m distances versus P-BOMs (Lysholm, Tegner, VAS, IKDC, KOOS, MARX, Noyes, SARS, and FORSS) using a combination of total and components scores with ACLR individuals. From these four studies, 13 correlations were reported comparing hop-based tests/outcome versus P-BOMs (as above). From these 13 correlations, 8 correlation coefficient values were significant ($p< 0.05$).

ACLR:

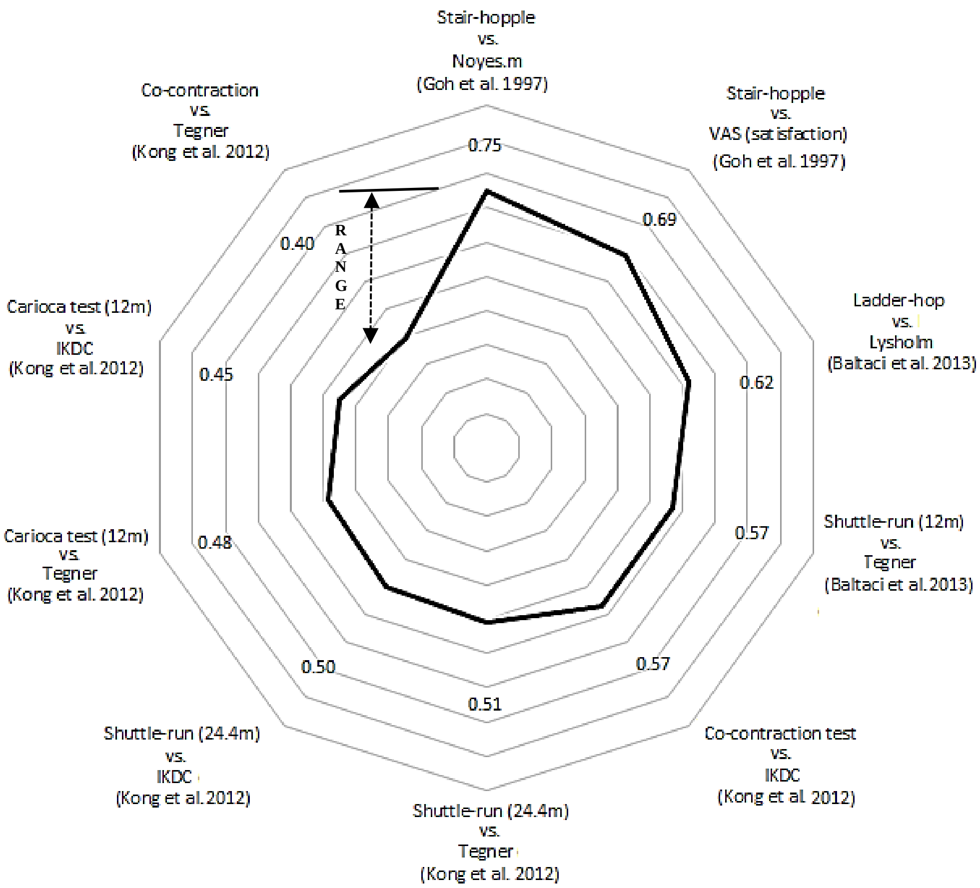
The several of the correlational relationships were found between a moderate to high relationship. The highest correlation coefficient values were found for VAS (knee satisfaction) and Noyes (modified) at a timed 6 m distances ($r = 0.72$, $p< 0.05$; $r_s= 0.62$, $p< 0.05$, respectively). Similarly, slightly lower relationships were found at 12 m, respectively, with the same P-BOMs from the same study (knee satisfaction: $r = 0.56$, $p< 0.05$, n=20; Noyes (modified): $r = 0.56$, $p< 0.05$, n=20) (Goh et al., 1997). Overall, these results suggest that a moderate to high correlations were found between timed-single-leg-hop-test for 6 m and 12 m distances for the (VAS) knee satisfaction and modified Noyes P-BOMs.

The remaining four significant ($p< 0.05$) correlations ([timed 6 m versus Noyes: $r = 0.31$, $p< 0.05$], [timed 6 m versus IKDC (hop subscale score): $r_s= 0.30$, $p= 0.03$], [timed 10 m versus Tegner: $\tau= 0.31$, $p< 0.05$], [timed 10 m versus SARS: $\tau= 0.22$, $p< 0.05$]) were either low, or were not correlated, suggesting that the SARS P-BOM was not correlated with the timed single-leg-hop test/outcome at 10 m distance, however, the Noyes (modified), IKDC (hop subscale/component score), and the Tegner P-BOMs were very weakly correlated (≤ 0.31).

The range of all correlation coefficients was calculated from all of the significant correlations between P-BOMs versus C-BOMs (hop-based tests/outcomes performed at 6 m, 10 m and 12 m distances), overall ranging from $r = 0.31 - 0.72$, $r_s= 0.3$, and $T= 0.22 - 0.31$.

P-BOMS VERSUS AGILITY TESTS/OUTCOMES (TIMED).

Three studies reported using a number of agility (C-BOMs: Stairs-hopple; Ladder-hop; Carioca [12m]; Co-contraction; Shuttle-run; Stairs and ladder-step) versus P-BOMs (Noyes [modified], VAS, Lysholm, Tegner, and IKDC) (Goh et al., 1997; Baltaci et al., 2013; Kong et al., 2012). The classification of the C-BOMs as agility tests is in order that these outcomes are not directly assessed by hop/jump performance, but assessed with both limbs simultaneously, with outcome using a combination of single-steps, side-steps and more functional activities. From these three studies, 17 correlations were reported when comparing agility outcomes versus all P-BOMs. From these 17 correlations, 10 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (agility test/outcomes) versus all P-BOMs are discussed separately.



Significant correlations for P-BOMs versus agility outcomes (Stairs-hopple [22-steps]; Ladder [20-hops]; Carioca [12 m]; Co-contraction; Shuttle-run [12 m and 24.4 m]; Stairs-step) tests evaluated by time.

Goh et al., (1997) reported two correlations that significantly correlated with the timed-stairs-hopple-test when evaluated with the P-BOMs (overall knee satisfaction: $r = 0.69$, $p < 0.05$, $n=20$); Noyes [modified]: $r = 0.75$, $p < 0.05$, $n=20$); suggesting moderate and high relationships, respectively. The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs and timed-stair-hopple test. Correlational coefficients ranged from 0.69 to 0.70.

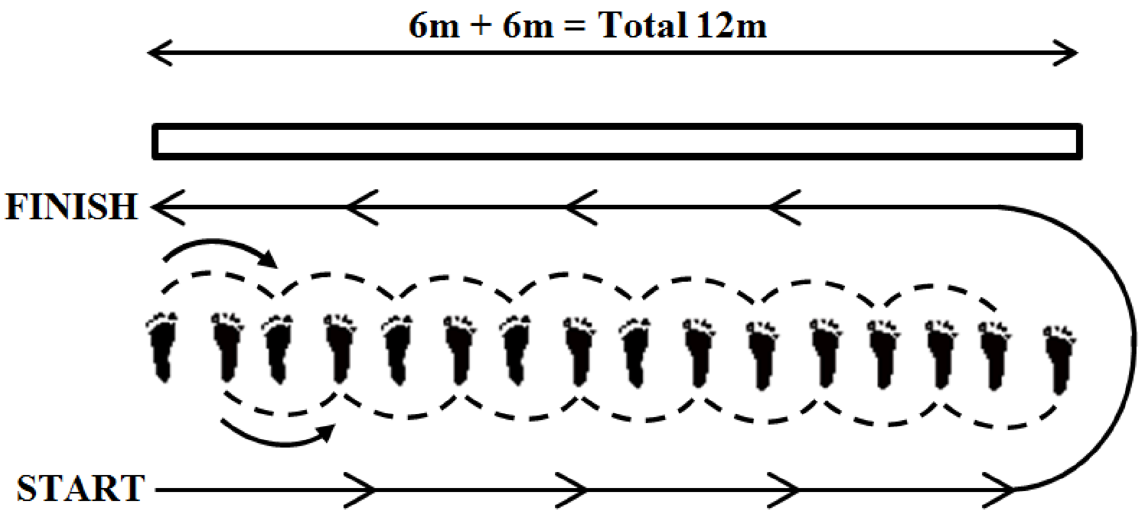
P-BOMS VERSUS LADDER-HOP TEST/OUTCOMES ASSESSED BY TIME.

One study reported using the ladder-hop test assessed by time versus two P-BOMs (Lysholm, Tegner) (Baltaci et al., 2012). The timed-ladder-hop-test is performed by a participant standing on a single leg, and participants are asked to jump forwards as fast as possible hopping using the same leg, furthermore, each hop must land in between ten of the rungs of a ladder and return to the starting point in between another 10 rungs (total of 20 hops between rungs). When the participant has completed the designated procedure, the time to complete this task would be recorded.

In only this study (Baltaci et al., 2012), two correlations were reported when assessing the relationship between two P-BOMs (Lysholm, Tegner) with the timed-ladder-hop-test. From these two correlations, only one correlation coefficient value was significant ($p < 0.05$). The P-BOMs that were significantly correlated with the timed-ladder-hop-test were the Lysholm ($r_s = 0.62$, $p < 0.05$, $n=15$); suggesting a moderate positive correlation.

P-BOMS VERSUS CARIOCA TEST OVER 12 M (TIMED).

One study reported using the timed-Carioca test over 12 m distance (Kong et al., 2012). The timed-Carioca tests over a 12m distance are carried out by a participant standing on both legs at a starting point. The participant is instructed to side step sideways by crossing their legs to a distance 6 m away, and returning to the starting point in the same manner. The time to complete this task would be recorded.

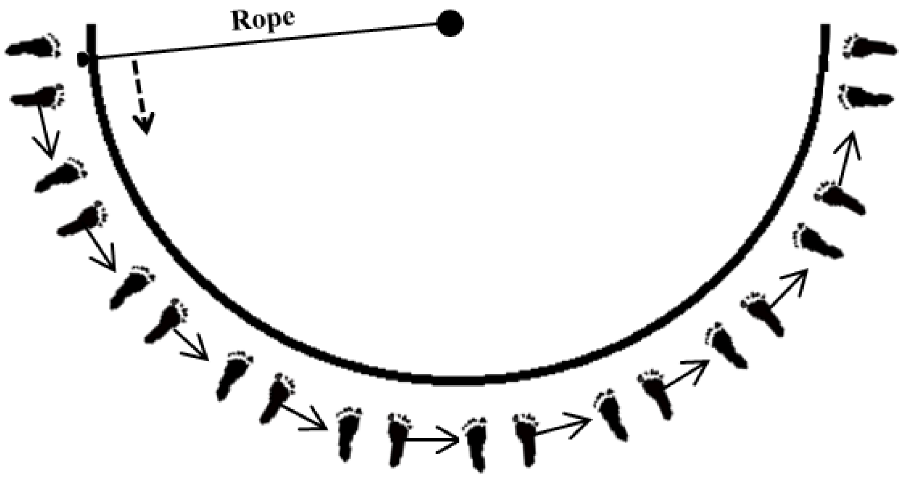


Schematic of Carioca time-test over 12 m distance (Source: Author's own diagram).

From this one study, three correlations were reported when evaluating timed-Carioca test versus P-BOMs (Lysholm, IKDC, and Tegner). From these three correlations, two correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the timed-Carioca test over a 12 m distance were IKDC ($r = 0.45$, $p = 0.012$, $n=30$) and Tegner ($r = 0.48$, $p = 0.007$, $n=30$); suggesting low positive correlations (Kong et al., 2012). The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs versus timed-Carioca test over 12 m distance; correlational coefficients ranged from $r = 0.45$ to 0.48.

P-BOMS VERSUS CO-CONTRACTION TEST/OUTCOME (TIMED).

One study reported using timed co-contraction test (Kong et al., 2012). The timed co-contraction is performed by a participant standing on both legs at a starting point. The participant is attached or secured to a belt (or similar fitting device) around the participant's waist. This belt is attached to a length of rope [length predefined for each individual setting] and anchored to a wall. There will be a semicircle with a defined radius, and the participant, standing with his or her toes on the line of the semicircle, is asked to run along the semi-circular line in a side-step or shuffle-fashion [direction right to left, and then again direction left to right]. The time to complete this task would be recorded.



Schematic of co-contraction time-test/outcome (Source: Author's own diagram).

From this one study (Kong et al, 2012), three correlations were reported when evaluating timed co-contraction test versus P-BOMs (Lysholm, IKDC, and Tegner). From these three correlations, two correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the timed co-contraction were the IKDC ($r = 0.57$, $p = 0.001$, $n=30$) and Tegner ($r = 0.40$, $p = 0.03$, $n=30$); suggesting a positive low to moderate correlation. The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs versus timed co-contraction test. Correlational coefficients ranged from (r) - 0.40 to - 0.57.

P-BOMS VERSUS SHUTTLE-RUN-TEST/OUTCOME (TIMED).

Two studies reported using timed-shuttle-run tests over 12 m and 24.4 m distances, respectively (Baltaci et al., 2013; Kong et al., 2012). Within each specific timed-shuttle-run test, participants were asked to run from a starting position to a finishing point over a total 12 m and 24.4 m distances, respectively. Participants were instructed to run as fast as they could, slow down just before the finish line, make a sudden stop and turn, and run back to the starting point. The time to complete this task would be recorded for each of the shuttle run distances.

From these two studies (Baltaci et al., 2013; Kong et al., 2012), five correlations were reported evaluating timed-shuttle-run tests versus P-BOMs (Lysholm, IKDC, and Tegner). From these five correlations, three correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the timed-shuttle-run test at 12 m distance was the Tegner ($r_s = 0.57$, $p < 0.05$, $n=15$), suggesting a positive moderate correlation (Baltaci et al., 2012). When evaluating the relationship between timed-shuttle-run test at 24.4 m distance with the same Tegner P-BOM, a significant correlation coefficient value of $r = -0.51$ ($p = 0.004$, $n=30$) was found (Kong et al., 2012); suggesting positive and negative moderate correlations, respectively. When the IKDC was correlated with the timed-shuttle-run test over 24.4 m distance in ACLR patients, the correlation coefficient was reported as $r = -0.50$ ($p = 0.004$, $n=30$) (Kong et al., 2012); suggesting a negative moderate correlation.

The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs versus timed-shuttle-run tests over 12 m and 24.4 m distances, respectively. Correlational coefficients ranged from (r) -0.50 to 0.57.

P-BOMS VERSUS STAIRS-STEP-TEST/OUTCOME (TIMED).

One study reported using timed-stair-step test (Baltaci et al., 2012). Participants were asked to climb up and down a set of ten steps on a set of stairs as fast as possible. The time to complete this procedure would be measured and recorded. From this one study, two correlations were reported when evaluating timed-stair-step test with P-BOMs (Lysholm and Tegner). From these three correlations, no correlation coefficient values were significant (p< 0.05); reporting no significant relationships between P-BOMs (Tegner and Lysholm) versus timed-stair-step outcomes.

SUMMARY:

From the 30 included studies reviewed, the following C-BOMs (stairs-hopple, ladder-hop, Carioca test, co-contraction test, Shuttle-run-tests, and stairs-step-test) outcomes were assessed versus P-BOMs (Lysholm, IKDC, Tegner, Noyes (modified), and knee satisfaction evaluated by the VAS) with only ACLR individuals. From these three studies (Goh et al., 1997; Baltaci et al., 2013; Kong et al., 2012), 17 correlations were reported when comparing agility outcomes versus P-BOMs. From these 17 correlations, 10 correlation coefficient values were significant (p< 0.05).

The highest correlation coefficient values were reported from the timed-hopple C-BOMs versus P-BOMs of modified Noyes (r = 0.75; p< 0.05; n=20) and overall knee satisfaction (VAS) (r = 0.69; p< 0.05; n=20) (Goh et al., 1997). The second highest relationship was found between the timed-ladder-hop-test versus the Lysholm P-BOM (rs= 0.62; p< 0.05; n=0.62). Meanwhile, the third highest correlations were reported from the co-contraction and shuttle-run at 12m C-BOMs (IKDC: r = -0.57, p= 0.001, n=30; Tegner: rs= 0.57, p< 0.05, n=15, respectively) (Kong et al., 2013; Baltaci et al., 2013). Similarly, Shuttle-run outcomes at 24.4 m reported slightly lower relationships (Tegner: r = -0.51, p= 0.004, n=30; IKDC: r = 0.50; p= 0.004, n=30) (Kong et al., 2012), whereby, all of the aforementioned values suggest moderate to high correlations reported.

The remaining correlations [Carioca test (12 m) versus Tegner (r = - 0.48, p= 0.007, n=30), Carioca test (12 m) versus IKDC (r = - 0.45, p= 0.012, n=30), Co-contraction versus Tegner (r = - 0.40, p= 0.030, n=30)], suggest low correlations (Kong et al., 2012). No correlation coefficient values were significant (p< 0.05) between P-BOMs (Tegner and Lysholm) versus timed-stair-step outcomes.

The range of all correlation coefficients was calculated from all of the significant correlations between P-BOMs versus C-BOMs (agility outcomes), overall ranging from rs= 0.57 to 0.62 and r = -0.40 to 0.75.

P-BOMS VERSUS ASSESSMENT FOR KNEE MEASUREMENT/STABILITY:

Fifteen studies from the total of 30 studies reported within this review evaluated knee laxity measurements with C-BOMs, either using knee arthrometers (KT-1000, KT-2000, and CA-4000), pivot-shift, manual Lachman, lateral-pivot-shift, and anterior-draw (Chia and Chok, 1999; Harter et al., 1988; Hrubesch et al., 2000; Kocher et al., 2004; Neeb et al., 1997; Lephart et al., 1992; Risberg et al., 1999b; Risberg et al., 1999c; Ross et al., 2002 ; Tyler et al., 1999; Sernert et al., 1999; Gleeson et al., 2008; Yates et al., 2016 [under review]; Snyder-Mackler et al., 1997; Harilainen et al., 1995). From these 15 studies, 99 correlations were reported when comparing the knee laxity measurements (as above) versus numerous P-BOMs (Tegner, Lysholm, Marshall, OAK, [KOS, ADLS, SAS], 10-PT, ARS, Bi-POMS, Cincinnati, ERAIQ, Feagin & Blake, FORSS, GKS, IAKS, IKDC, KFR, Performance Profile, POPF, SARS, VAS, and Zarins & Rowe) From these 99 correlations, only 13 correlation coefficient values were significant for the KT-1000 (p< 0.05).

The remaining arthrometers (i.e., KT-2000 and CA-4000) and measurements of knee laxity were found to be non-significant. From the large number of P-BOMs initially found, only several P-BOMs: Bi-POMS, POPF, Tegner, IKDC, Performance Profile, and ERAIQ were found to significantly correlate (p< 0.05).

P-BOMS VERSUS KT-1000.

Thirteen studies reported using KT-1000 arthrometry knee measurements versus a number of P-BOMs (Bi-POMS, POPF, Tegner, IKDC, Performance Profile, and ERAIQ) (Chia & Chok, 1999, Harter et al., 1988, Hrubesch et al., 2000, Kocher et al., 20041, Neeb et al., 1997, Lephart et al., 1992, Risberg et al., 1999b, Risberg et al., 1999c, Ross et al., 2002, Tyler et al., 1999, Sernert el al., 1999, Gleeson et al., 20083, Yates et al., 2016 [under review]). From these 13 studies, 61 correlations were reported comparing P-BOMs (as above) with KT-1000 measurements.

In one study, two correlations were reported in ACLR patients, correlating the IKDC ('hop-test' subscale/component score) and the IKDC ('symptoms' subscale/component score) both evaluating patients at three months post-surgery with the KT-1000 (Chia and Chok, 1999). Correlation coefficients were $\tau = 0.52$ ($p < 0.01$, n=21) and $\tau = 0.41$ ($p < 0.05$, n=21), respectively. This suggested a positive low correlation between the IKDC ('symptoms' subscale/component score) and the KT-1000, while a positive moderate correlation was found between the IKDC ('hop-test' subscale/component score).

In one study, the POPF was evaluated with the KT-100 (at 90N) in ACLR patients. A correlation coefficient value of $r = -0.31$ ($p < 0.01$, n=51) was reported (Harter et al., 1988), suggesting a positive low correlation between the POPF and the KT-1000.

In one study, when the Tegner was correlated with the KT-1000 in ACLR patients, the correlation coefficient was reported as $\tau = 0.25$ ($p < 0.05$, n=30) (Neeb et al., 1997); suggesting no or negligible correlation.

In one study, eight correlations were reported in ACLR patients (Gleeson et al., 2008). The ERAIQ, BI-POMS and Performance Profile were evaluated with a custom built arthrometry system (similar to the KT-1000) at four time points: pre-surgery, 6, 8 and 10 weeks post-surgery. Firstly, when evaluating the Bi-POMS with KT-1000, the Bi-BOMS had significant correlations at 8 weeks post-surgery only for the subscale/component score 'tired-energetic' ($r = -0.87$, $p < 0.01$, n=9), 'depressed-elated' ($r = -0.85$, $p < 0.01$, n=9), and 'hostile-agreeable' ($r = -0.72$, $p < 0.05$, n=9); suggesting a high positive correlation between Bi-POMs and KT-1000. In the same study, the ERAIQ also reported significant correlations with the KT-1000 for 'discouraged' ($rs = -0.79$, $p < 0.05$, n=9) and 'pain' ($r = -0.78$, $p < 0.05$, n=9) subscales/component score at 8 and 10 weeks, respectively. These correlations are suggesting high positive correlations between ERAIQ and the KT-1000.

Finally, in the same study, the Performance Profile using an elicited emotion profile reported significant correlations with the KT-1000 at pre-surgery ($rs = 0.68$, $p < 0.05$, n=9), 8 ($rs = .72$, $p < 0.05$, n=9), and 10 weeks post-surgery ($rs = 0.70$, $p < 0.05$, n=9). This suggested a moderate correlation between the Performance Profile (at pre-surgery) with the KT-1000, while positive high correlations were found between the Performance Profiles at 8- and 10 weeks post-surgery with the KT-1000.

In the last study (Yates et al., 2016 [under review]), the Performance Profile using an elicited physical profile reported no significant correlations with the KT-1000. However, when the Performance Profile from the assessments at weeks 8 and 10 were correlated with antecedent scores from arthrometer at weeks 6 and 8, respectively, significant relationships were found ($rs = 0.68$ to 0.80; $p < 0.05$); suggesting that the time points of these assessments computed positive moderate correlations between the Performance Profile and knee laxity measurements.

The range of correlation coefficients was calculated from all of the significant correlations between P-BOMs and KT-1000 [IKDC: ($\tau = .41$ to $.52$); Bi-POMS: ($r = -.82$ to $-.87$); ERAIQ: ($rs = .79$; $r = .78$); POPF ($r = -.31$)]; PP: ($rs = .68$ to $.72$); suggesting that overall, there was a low to very high correlation between P-BOMs and KT-1000. A significant relationship was found for the Tegner ($p < 0.05$), however, this relationship was deemed none or negligible.

P-BOMS VERSUS KT-2000 TEST/OUTCOME.

One study reported to evaluate knee laxity measurements from KT-2000 versus P-BOMs (Lysholm, KOS, and GKS) in ACLD patients (Snyder-Mackler et al., 1997). From this study, 8 correlations were reported; however, none of the correlations were significant ($p < .05$). The results suggest no concomitant relationships were found concurrently between KT-2000 and versus any of P-BOMs.

P-BOMS VERSUS CA-1000 TEST/OUTCOME.

One study reported to evaluate knee laxity measurements from CA-4000 versus P-BOMs (Lysholm and Tegner) in ACLD patients (Harilainen et al., 1995). From this study, 2 correlations were reported, however, none of the correlations coefficient values were significant ($p < 0.05$). The results suggest no concomitant relationships were found concurrently between CA-1000 and versus any of the P-BOMs.

P-BOMS VERSUS PIVOT-SHIFT TEST/OUTCOME.

One study reported to evaluate Pivot-shift-test versus P-BOMs (Lysholm, Tegner, SARS, and FORSS) in ACLR patients (Neeb et al., 1997). From this study, four correlations were reported, however, none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between pivot-shift test and versus any of P-BOMs.

P-BOMS VERSUS MANUAL LACHMAN-TEST/OUTCOME.

Three studies reported to evaluate manual Lachman-test versus P-BOMs (SARS, FORSS, Lysholm, Tegner, FAS, Tegner, IKDC, VAS, KFR, ARS, POPF, and 10PT) in ACLR patients (Neeb et al., 1997; Seto et al., 1988; Sernert et al., 1999; Harter et al., 1988). From these studies, 18 correlations were reported; however, none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between manual Lachman-test and versus any of P-BOMs.

P-BOMS VERSUS LATERAL-PIVOT-SHIFT TEST/OUTCOME.

One study reported to evaluate lateral-pivot-shift test versus P-BOM (FAS) in ACLR patients (Seto et al., 1988). From this study, 2 correlations were reported; however, none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between lateral-pivot-shift and versus any of P-BOMs.

P-BOMS VERSUS ANTERIOR-DRAW TEST/OUTCOME.

One study reported to evaluate anterior-draw test versus P-BOMs (FAS) in ACLR patients (Seto et al., 1988). From this study, four correlations were reported, however, none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between anterior-draw test and versus any of the P-BOMs.

SUMMARY:

Fifteen studies from the total of 30 studies reported within this review evaluated knee laxity measurements (C-BOMs) with knee arthrometry (KT-1000, KT-2000, and CA-4000), and manual/physically applied pivot-shift, Manual Lachman, Lateral-pivot-shift, and Anterior-draw techniques. From these 15 studies, 99 correlations were found evaluating knee laxity measurements (as above) versus numerous P-BOMs.

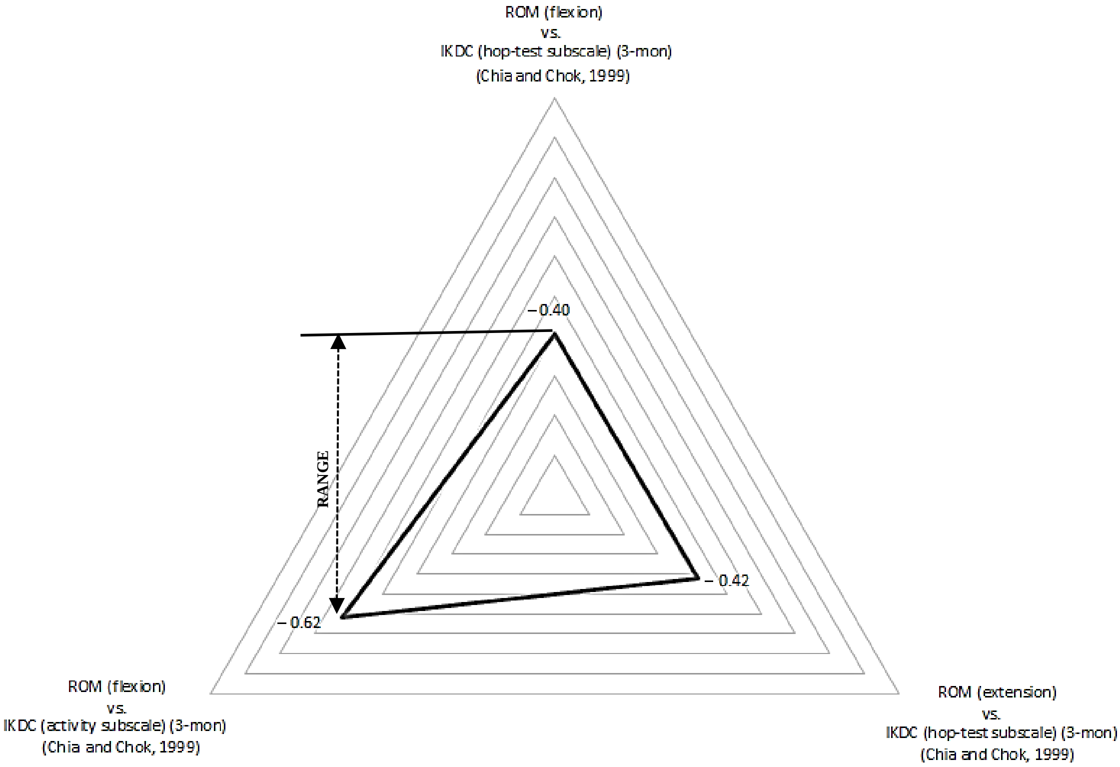
From these 99 correlations, only 13 correlation coefficient values were significant versus KT-1000 ($p< 0.05$). The P-BOMs that were significantly correlated with the KT-1000 were the IKDC ('symptoms' subscale/component score, at three months post-surgery: $\tau= 0.41$, $p= 0.05$, $n=21$), IKDC ('hop-test' subscale/component score, at three months post-surgery: $\tau= 0.515$, $p< 0.01$, $n=21$), Tegner ($\tau= 0.25$, $p< 0.05$, $n=30$), POPF ($r = -0.31$, $p< 0.01$, $n=51$), ERAIQ (discouraged, at 8 weeks post-surgery, $rs= 0.79$, $p< 0.05$, $n=9$), ERAIQ (pain, at 10 weeks post-surgery, $r = 0.78$, $p< 0.05$, $n=9$), Bi-POMS (tired-energetic, at 8 weeks post-surgery, $r = -0.87$, $p< 0.01$, $n=9$), Bi-POMS (depressed-elated, at 8 weeks post-surgery, $r = -0.85$, $p< 0.01$, $n=9$), Bi-POMS (hostile-agreeable, at 8 weeks post-surgery, $r = -0.71$, $p< 0.05$, $n=9$), Bi-POMS (hostile-agreeable, at 8 weeks post-surgery, $r = -0.71$, $p< 0.05$, $n=9$), Performance Profile (emotional profile at pre-surgery, $rs= 0.68$, $p< 0.05$, $n=9$); Performance Profile (emotional profile at 8 weeks post-surgery, $rs= 0.72$, $p< .05$, $n=9$); Performance Profile (emotional profile at 10 weeks post-surgery, $rs= .70$, $p< 0.05$, $n=9$); and Performance Profile (physical profile at 10 weeks post-surgery ($rs= 0.68$, $p< 0.05$, $n=9$).

The remaining arthrometers systems (i.e., KT-2000 and CA-4000) and manual/physically applied pivot-shift, Manual Lachman, Lateral-pivot-shift, and Anterior-draw techniques were found to be non-significant.

P-BOMS VERSUS CLINICAL TESTS/OUTCOMES.

Within the 30 reviewed studies, five studies (Seto et al., 1988; Sernert et al., 1999; Chia and Chok, 1999; Risberg et al., 1999c; Risberg et al., 1999b) reported to use a range of outcome measures that, for the purpose of this review, are classified as clinical tests/outcomes. These include: range of motion [ROM], knee ligaments tests for varus and valgus abnormalities, kneeling and kneel-walking, and loss of anterior knee sensitivity tests. From these 5 studies, 50 correlations were found evaluating clinical outcomes (as above) versus P-BOMs (FAS, Tegner, Lysholm, IKDC, VAS, and Cincinnati.

From these 50 correlations, only 3 correlation coefficient values were significant versus ROM tests/outcomes ($p < 0.05$). The remaining clinical tests/outcomes (i.e., knee ligaments tests for varus and valgus abnormalities, kneeling and kneel-walking, and loss of anterior knee sensitivity) remained non-significant.



Significant correlations ($p < 0.05$) for P-BOMs (FAS, Tegner, Lysholm, IKDC, VAS, Cincinnati) versus clinical tests (range of motion [ROM], knee ligaments tests for varus and valgus abnormalities, kneeling and kneel-walking, and loss of anterior knee sensitivity tests).

P-BOMS VERSUS RANGE OF MOTION (ROM) TESTS/OUTCOMES.

Three studies reported to evaluate range of motion (ROM) of flexion and extension measurement tests/outcomes with P-BOMs (IKDC and Cincinnati) with ACLR individuals only (Chia and Chok, 1999; Risberg et al., 1999b; Risberg et al., 1999c). From these three studies, 28 correlations were reported by evaluating ROM versus P-BOMS. From these 28 correlations, only three correlation coefficient values were significant ($p < 0.05$).

The IKDC subscales/component score for 'hop-test' versus ROM (flexion and extension) measurements at 3-month post-surgery reported low negative correlations ($\tau = -0.40$, $p < 0.05$, $n = 21$ and $\tau = -0.42$, $p < 0.05$, $n = 21$, respectively). The remaining significant correlation was for the IKDC 'activity' subscale/component score evaluated versus ROM (flexion) at 6-months post-surgery ($\tau = -0.62$, $p < 0.01$, $n=21$); suggesting that overall, there was a low negative correlation between IKDC subscales/component score of 'activity' versus ROM at 6-months post-surgery.

P-BOMS VERSUS VARUS AND VALGUS TESTS.

One study reported to evaluate valgus and varus tests/outcome performed at 0 to 30° for knee extension and flexion versus P-BOMs (FAS) in ACLR patients (Seto et al., 1988). The FAS P-BOM is a total combined score of the Lysholm and Noyes P-BOMs. From this one study, 8 correlations were reported evaluating valgus and varus tests/outcome versus P-BOM. From these 8 correlations, none of the correlation coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between varus and valgus outcomes versus FAS.

From this one study, 7 correlations were reported evaluating kneeling and knee-walking outcome versus P-BOM. From these 7 correlations, none of the correlation coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between kneeling and knee-walking outcome versus all P-BOMs.

P-BOMS VERSUS DONOR-SITE SENSITIVITY-TESTS.

One study reported to evaluate donor-site-sensitivity test performed by a single assessor with P-BOMs (Tegner, Lysholm, IKDC, and VAS) in ACLR patients (Sernert et al., 1999). The donor-site-sensitivity test was evaluated by examining the loss of anterior knee sensitivity. This was achieved by an assessor palpating the anterior aspect of the injured and non-injured knee; the knee sensitivity score was measured in square centimetres (m^2).

From this one study, 7 correlations were reported evaluating donor-site-sensitivity outcome versus P-BOM. From these 7 correlations, none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between donor-site-sensitivity outcomes versus all P-BOMs.

SUMMARY:

Five studies (Seto et al., 1988; Sernert et al., 1999; Chia and Chok, 1999; Risberg et al., 1999c; Risberg et al., 1999b) reported evaluating a range of C-BOMs that for the purpose of this review are classified as clinical tests/outcomes. These include: range of motion [ROM] tests, knee ligaments tests for varus and valgus abnormalities, kneeling and kneel-walking, and loss of anterior knee sensitivity tests. From these 5 studies, 50 correlations were found evaluating clinical outcomes (as above) versus P-BOMs (FAS, Tegner, Lysholm, IKDC, VAS, and Cincinnati). From these 50 correlations, only 3 correlation coefficient values were significant versus ROM tests/outcomes ($p< 0.05$). The remaining clinical tests/outcomes (i.e., knee ligaments tests for varus and valgus abnormalities, kneeling and kneel-walking, and loss of anterior knee sensitivity) remained non-significant.

The IKDC subscales/component score for 'hop-test' versus ROM (flexion and extension) measurements at 3-month post-surgery reported low negative correlations ($\tau= -0.40$, $p< 0.05$, $n= 21$ and $\tau= -0.42$, $p< 0.05$, $n= 21$, respectively). The remaining significant correlation was for the IKDC 'activity' subscale/component score evaluated versus ROM (flexion) at 6-months post-surgery ($\tau= -0.62$, $p< 0.01$, $n= 21$); suggesting that overall, there was a low negative correlation between IKDC subscales/component score of 'activity' versus ROM at 6-months post-surgery. The range of all correlation coefficients was calculated from all of the significant correlations between P-BOMs versus C-BOMs (clinical outcomes), overall ranging from $\tau= -40$ to -0.42.

P-BOMS VERSUS PROPRIOCEPTION TESTS/OUTCOMES.

Five studies (Borsa et al., 1998; Risberg et al., 1999a; Trulsson et al., 2010; Harter et al., 1988; Yates et al., 2016 [under review]) were found to correlate proprioception tests/overcomes (TDPM, TSP, Performance Profile, and JPS) versus P-BOMs (Lysholm, Cincinnati, KOOS, KFR, POPF, ARS, 10PT, and Performance Profile). From these five studies, 14 correlations were found comparing the proprioception tests with P-BOMs (as above). From these 14 correlations, only two correlation coefficient values were significant ($p< 0.05$). Each reported correlation between C-BOMs (proprioception tests/overcomes versus all P-BOMs are discussed separately).

P-BOMS VERSUS THRESHOLD TO DETECT PASSIVE MOTION (TDPM).

Two studies reported to evaluate TDPM versus P-BOMs (Lysholm, Cincinnati, and KOOS) in ACLD and ACLR individuals (Borsa et al., 1998; Risberg et al., 1999a). From these two studies, 8 correlations were reported evaluating TDPM versus P-BOMs. From these 8 correlations none of the correlations coefficient values were significant ($p< 0.05$). The results suggest no concomitant relationships were found concurrently between TDPM versus P-BOMs.

P-BOMS VERSUS TEST FOR SUBSTITUTION PATTERNS (TSP).

One study reported to evaluate TSP versus P-BOMs (KOOS: 'sport' subscale/component score) in ACLR individuals (Trulsson et al., 2010). A correlation coefficient value of rs= -0.43, (p= 0.001, n= 53) was found; suggesting a negative low correlation between the KOOS ('sport' subscale/component score) and the TSP.

P-BOMS VERSUS REPRODUCTION OF PASSIVE POSITIONING (RPP).

One study reported to evaluate Performance Profile versus P-BOMs (KFR, POPF, ARS, and 10PT) in ACLR individuals (Harter et al., 1988). From this study, 4 correlations were reported evaluating Performance Profile versus P-BOMs. From these 4 correlations, none of the correlation coefficient values were significant (p< 0.05). The results suggest no concomitant relationships were found concurrently between Performance Profile versus P-BOMs.

P-BOMS VERSUS JOINT POSITION SENSE (JPS).

One study reported to evaluate JPS versus P-BOM (Performance Profile) in ACLR individuals (Yates et al., 2016 [under review]). A correlation coefficient value of rs= 0.70, (p< 0.05, n= 9) was found; suggesting a positive high correlation between the Performance Profile and JSP.

SUMMARY:

Five studies were found to correlate proprioception tests/overcomes (TDPM, TSP, Performance Profile, and JPS) versus a number of P-BOMs (Lysholm, Cincinnati, KOOS, KFR, POPF, ARS, 10PT, and Performance Profile). From these five studies, 14 correlations were found comparing the proprioception tests with P-BOMs (as above). From these 14 correlations, only two correlation coefficient values were significant (p< 0.05). The highest correlation reported within this section, and is reported as a high relationship, was with the Performance Profile, that was significantly correlated with JSP (rs= 0.70, p< 0.05, n= 9). Furthermore, the final significant remaining correlation was the C-BOMs TSP when correlated with the KOOS ('sport' subscale/component score: rs= -0.43, p= 0.001, n= 53) P-BOM, a negative and low correlation was found.

P-BOMS VERSUS BALANCE-TESTS/OVERCOMES.

Two studies (Borsa et al., 1998; Park et al., 2010) were found to correlate balance tests/overcomes (Dynamic postural stability, and Static balance index [SBI]) versus P-BOMs (Lysholm, Cincinnati, and IKDC) for ACLD and ACLR individuals. From these two studies, 4 correlations were found comparing balance tests/overcomes versus P-BOMs (as above). From these four correlations, only two correlation coefficient values were significant (p< 0.05). Each reported correlation between C-BOMs (balance tests/overcomes) versus P-BOMs are discussed separately.

P-BOMS VERSUS STATIC BALANCE INDEX (SBI) TEST/OUTCOME.

One study reported to evaluate SBI versus P-BOMs (Lysholm, IKDC) in ACLD individuals (Borsa et al., 1998). From this study, two correlations were reported evaluating SBI versus P-BOMs. From these two correlations none of the correlation coefficient values were significant (p< 0.05). The results suggest no concomitant relationships were found concurrently between SBI versus P-BOMs.

P-BOMS VERSUS DYNAMIC POSTURAL STABILITY TEST/OUTCOME.

One study reported to evaluate dynamic postural stability versus P-BOMs (Lysholm, IKDC) in ACLR individuals (Park et al., 2010). Correlation coefficients were calculated from all of the significant correlations between P-BOMs and dynamic postural stability [(IKDC: rs= 0.52, p= 0.05) and (Lysholm: rs= -0.49, p= 0.01)]; suggesting that overall, there was a moderate correlation between P-BOMs and dynamic postural stability.

SUMMARY:

Two studies (Borsa et al., 1998; Park et al., 2010) were found to correlate balance tests/overcomes (Dynamic postural stability, and Static balance index [SBI]) versus P-BOMs (Lysholm, Cincinnati, and IKDC) for ACLD and ACLR individuals. From these two studies, 4 correlations were found comparing balance tests/overcomes versus P-BOMs (as above). From these four correlations, only two correlation coefficient values were significant ($p < 0.05$). The P-BOMs that were significantly correlated with the dynamic postural stability were the Lysholm (rs= -0.49, p= 0.001, n= 40) and the IKDC (rs= -.052, p= 0.05, n= 40); suggesting a moderate correlation, respectively. No relationships were found between SBI versus P-BOMs (Lysholm and IKDC) in ACLD individuals.

P-BOMS VERSUS DYNAMOMETRY TEST/OUTCOMES:

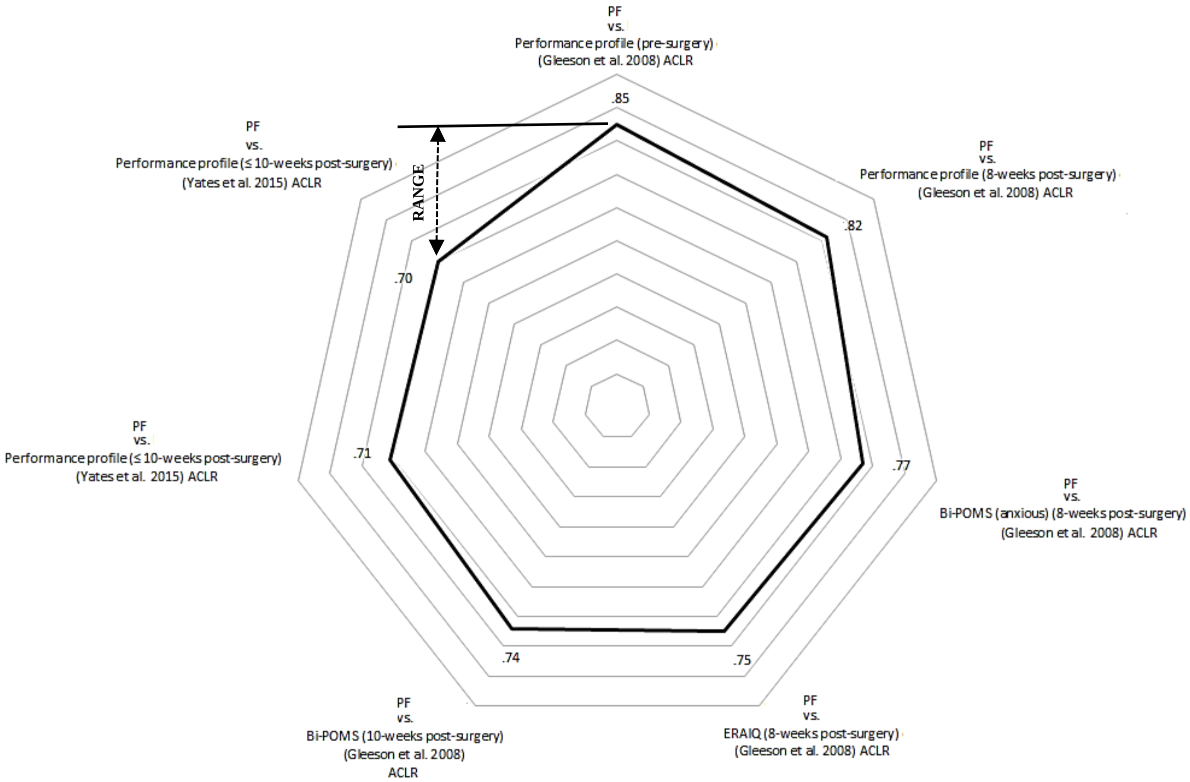
Sixteen studies reported using dynamometry to evaluate lower limb muscle strength/ performance versus P-BOMs (Lysholm, Noyes (modified), Tegner, Cincinnati, ERAIQ, FAS, IAKS, KFR, Performance Profile, POPF, [KOS, ADLS, SAS], 10PT, ARS, and Bi-POMS) (Baltaci et al., 2012; Borsa et al., 1998; Bryant et al., 2008a; Bryant et al., 2008b; Gleeson et al., 2008; Harilainen et al., 1995; Harter et al., 1988; Holm et al., 2000; Kannus, 1988; Lephart et al., 1992; Li et al., 1996; Risberg et al., 1999c; Ross et al., 2002; Seto et al., 1988; Wilk et al., 1994; Yates et al., 2016 [under review]). From these 16 studies, 125 correlations were reported when comparing dynamometry muscle strength/performance variables versus P-BOMs. From these 125 correlations, 62 correlation coefficient values were significant ($p < 0.05$).

Due to the large number of isokinetic dynamometer muscle contractions and parameters assessed (isometric, eccentric isokinetic, and concentric isokinetic) within the sixteen studies, isokinetic measurements were divided in the following categories: (1 :) Peak measurements; for example the most common found were Peak force (PF), peak torque [PT] and total work [TW] capacity; (2 :) Angle-specific measurements, which are isokinetic measurements produced at specific knee angles, therefore, allowing equitable comparisons between and within individuals; (3 :) Assessment of the acceleration and deceleration phases; (4 :) Neuromuscular indices of knee outcome measures. In the latter, the examination of such measures (i.e., EMD, RFD) could assist in the validation muscle function/recovery assessments and provides useful markers of return of neuromuscular function and potential markers for returning to sport (Knezevic et al., 2014). Each reported correlation between C-BOMs (dynamometry tests/overcomes) versus all P-BOMs are discussed separately. In addition, each of these isokinetic measurement groups (as above), the knee extensors and knee flexors, were also examined separately.

P-BOMS VERSUS DYNAMOMETRY: (1) PEAK MEASUREMENTS.

P-BOMS VERSUS PEAK FORCE (PF).

Three studies reported using peak measurements of Peak Force (PF) assessed by dynamometry to evaluate lower limb isometric muscle strength versus P-BOMs (Lysholm, Cincinnati, Bi-POMS, ERAIQ, and Performance Profile) (Borsa et al., 1998; Gleeson et al., 2008; Yates et al., 2016 [under review]). From these three studies, nine correlations were reported when comparing dynamometry (PF) versus P-BOMs for the knee flexors and knee extensors. From these nine correlations, seven correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: PF) versus P-BOMs are discussed separately for knee flexors and knee extensors.



Significant correlations (p< 0.05) for P-BOMs (Lysholm, Cincinnati, Bi-POMS, ERAIQ, and Performance Profile) versus peak measurements of Peak Force (PF) evaluated by dynamometry.

KNEE FLEXORS.

Two studies reported to evaluate PF (dynamometry) versus P-BOMs (Lysholm, Cincinnati, ERAIQ, Bi-POMS, and Performance Profile) in ACLD/ACLR individuals with the knee flexors (Borsa et al., 1998; Yates et al., 2016 [under review]). The first correlation was found between PF versus ERAIQ at 8 weeks post-surgery (r_s= 0.75, $p< 0.05$, n= 9) (Gleeson et al., 2008); suggesting a positive high correlation between ERAIQ and PF for the knee flexors with ACLR individuals. Similarly, within the same study, a two correlations case was found between PF versus Bi-BOMs at 8 weeks (anxious subscale: r_s= 0.77, $p< 0.05$, n= 9) and 10 weeks post-surgery (total score: r_s= 0.74, $p< 0.05$, n= 9); suggesting positive high correlations between Bi-POMS and PF for the knee flexors with ACLR individuals.

The remaining three correlations (PF versus Performance Profile) in ACLR individuals (Gleeson et al., 2008) found significant relationships concurrently between the Performance Profile versus PF at pre-surgery (r_s= 0.85, $p< 0.01$, n= 9), and at 8 weeks post-surgery (r_s= 0.82, $p< 0.01$, n= 9); suggesting positive high correlations between the Performance Profile and PF for the knee flexors.

No significant correlations were found between PF versus Cincinnati and Lysholm for knee flexors for ACLD individuals; the results suggest no concomitant relationships were found concurrently between PF versus P-BOMs.

KNEE EXTENSORS.

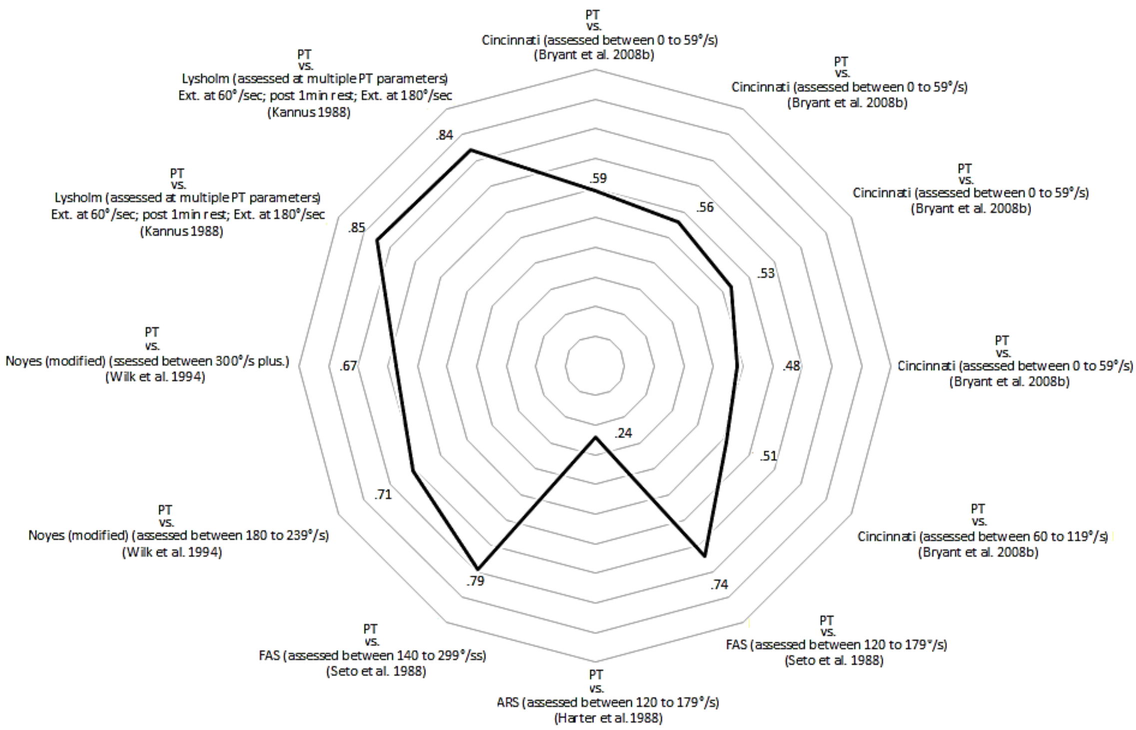
One study reported to evaluate PF (dynamometry) versus P-BOM (Performance Profile) in ACLR individuals with the knee extensors (Yates et al., 2016 [under review]). No significant relationships were found concurrently between the Performance Profiles versus PF at 6- and 8 weeks post-surgery. However, when Performance Profile total scores at weeks 8 and 10 were correlated with antecedent scores from PF at weeks 6 and 8, respectively, significant relationships were found (r_s= 0.70 and 0.70 ($p< 0.05$, n= 9); suggesting a positive high correlation between the Performance Profile and PF for the knee extensors.

P-BOMS VERSUS PEAK TORQUE (PT):

Eleven studies reported using peak measurements of peak torque (PT) assessed by dynamometry to evaluate lower limb peak torque muscle strength versus P-BOMs (Lysholm, Tegner, Cincinnati, FAS, IAKS, KFR, Noyes (modified), POPF, [KOS, ADLS, SAS], 10PT, and ARS) (Bryant et al., 2008b; Harilainen et al., 1995; Kannus, 1988; Lephart et al., 1992; Ross et al., 2002; Seto et al., 1988; Wilk et al., 1994; Harter et al., 1988; Baltaci et al., 2012; Bryant et al., 2008a; Li et al., 1996). From these eleven studies, 74 correlations were reported when comparing dynamometry (PT) versus P-BOMs for the knee flexors and knee extensors with ACLD/ACLR individuals. From these 74 correlations, 38 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: PT) and P-BOMs, which are discussed separately for knee flexors and knee extensors. In addition, several studies examined the relationship between PT with knee flexor and knee extensor ratios (i.e., H:Q ratio); these correlations will be further examined following this section.

KNEE EXTENSORS:

Six studies reported to evaluate PT (dynamometry) versus P-BOMs (Lysholm, Cincinnati, Noyes (modified), FAS, and ARS) in ACLD/ACLR individuals with the knee extensors (Bryant et al., 2008b; Seto et al., 1988; Harter et al., 1988; Seto et al., 1988; Wilk et al., 1994; Kannus, 1988). From these six studies, 24 correlations were reported when comparing dynamometry (PT) versus P-BOMs. From these 24 correlations, 12 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: PT) versus P-BOMs are discussed separately with each angular-specific measurements/ranges.



Significant correlations ($p < 0.05$) for P-BOMs (Lysholm, Cincinnati, Noyes (modified), FAS, and ARS) versus peak measurements of Peak Force (PF) evaluated by dynamometry in the knee flexors with ACLD and ACLR individuals.

P-BOMS VERSUS PT (ASSESSED BETWEEN 0 TO 59°/s).

One study (Bryant et al., 2008b) evaluated PT between 0 to 59°/s versus P-BOM (Cincinnati) in the knee extensors of ACLR individuals. Within 0 to 59°/s angle-specific measurements/ranges, the following correlation coefficients were found at 20-30°/s (r = 0.59, p= 0.016, n= 13), 30-40°/s (r = 0.56, p= 0.023, n= 13), 40-50°/s (r = 0.53, p= 0.030, n= 13), and 50-60°/s (r = 0.48, p= 0.047, n= 13); suggesting a positive low to moderate correlations between the Cincinnati and PT for the knee extensors.

P-BOMS VERSUS PT (ASSESSED BETWEEN 60 TO 119°/s).

One study (Bryant et al., 2008b) evaluated PT between 60 to 119°/s versus P-BOM (Cincinnati) in the knee extensors of ACLR individuals. Within 60 to 119°/s angle-specific measurements/ranges, the only following correlation coefficients were found at 60-70°/s (r = 0.51, p= 0.037, n= 13); suggesting positive moderate correlations between the Cincinnati and PT for the knee extensors.

P-BOMS VERSUS PT (ASSESSED BETWEEN 120 TO 179°/s).

Two studies (Seto et al., 1988; Harter et al., 1988) evaluated PT between 120 to 179°/s versus P-BOMs (FAS and ARS) in the knee extensors of ACLR individuals. Within 120 to 179°/s angle-specific measurement/ranges, two correlation coefficients were found to be significant (p< 0.5) at 120°/s for the FAS (r = 0.74, p< 0.05, n= 25) and ARS (r = 0.24, p= 0.05, n= 51); suggesting a positive high correlation was found between the FAS versus PT at 120°/s, while no- or negligible relationship was found between ARS versus PT at 120°/s in the knee extensors of ACLR individuals, respectively.

P-BOMS VERSUS PT (ASSESSED BETWEEN 180 TO 239°/s).

One study (Wilk et al., 1994) evaluated PT between 180 to 239°/s versus P-BOM (modified Noyes) in the knee extensors with ACLR individuals. Within 180 to 239°/s angle-specific measurements/ranges, the following correlation coefficients were found at 180°/s (r = 0.71, p= 0.01, n= 50); suggesting positive high correlations between the Noyes (modified) and PT at 180°/s for the knee extensors.

P-BOMS VERSUS PT (ASSESSED BETWEEN 240 TO 299°/s).

One study (Seto et al., 1988) evaluated PT between 240 to 299°/s versus P-BOM (FAS) in the knee extensors with ACLR individuals. Within 240 to 299°/s angle-specific measurements/ranges, the following correlation coefficients were found at 240°/s (r = 0.79, p= 0.01, n= 25); suggesting positive high correlations between the FAS and PT at 240°/s for the knee extensors.

P-BOMS VERSUS PT (ASSESSED BETWEEN 300°/s PLUS).

One study (Wilk et al., 1994) evaluated PT over 300°/s versus P-BOM (modified Noyes) in the knee extensors with ACLR individuals. Angle-specific measurements/ranges over 300°/s, the following correlation coefficients were found at 300°/s (r = 0.67, p= 0.05, n= 50); suggesting positive moderate correlations between the Noyes (modified) and PT at 300°/s for the knee extensors.

P-BOMS VERSUS PT (ASSESSED AT MULTIPLE PT PARAMETERS).

One study (Kannus et al., 1988) evaluated PT between multiple angular-specific measurements with a rest between (i.e., 60°/sec; post 1-min rest; 180°/sec) versus P-BOM (Lysholm) in the knee extensors of ACLD individuals. At this testing parameter (as above), two correlation coefficients were found to be significant (p< 0.5) for the Lysholm P-BOM: r = 0.84 (p< 0.001; n= 36) and rs= 0.85 (p< 0.001; n= 36); suggesting positive height correlations between the Lysholm and PT at multiple testing parameters for the knee extensors.

KNEE FLEXORS:

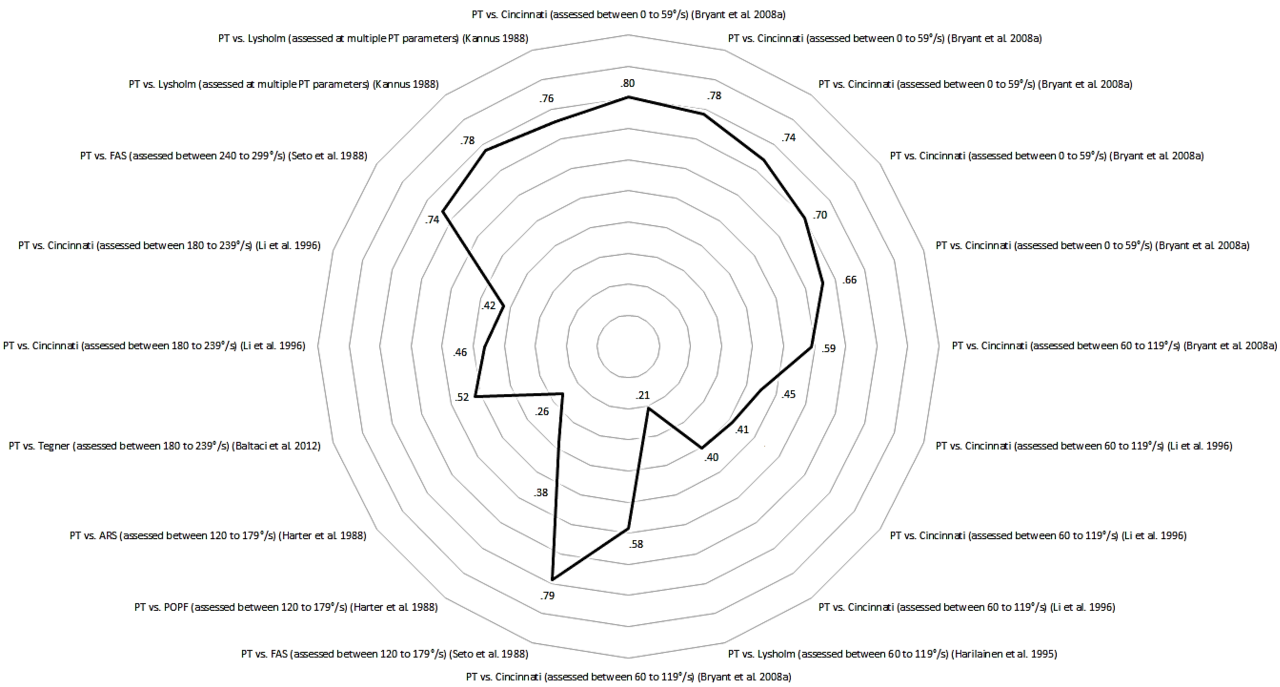
Seven studies reported to evaluate PT (dynamometry) versus P-BOMs (Tegner, Cincinnati, Lysholm, POPF, SARS, and FAS) in ACLD/ACLR individuals with the knee flexors (Baltaci et al., 2012; Bryant et al., 2008; Harilainen et al., 1995; Harter et al., 1988; Kannus, 1988; Li et al., 1996; Seto et al., 1988). From these seven studies, 50 correlations were reported when comparing dynamometry (PT) versus P-BOMs (as above). From these 50 correlations, 20 correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: PT) versus P-BOMs is discussed separately with each angular-specific measurements/ranges. In addition, several studies examined the relationship between PT with knee flexors and knee extensors ratios (i.e., H:Q ratio); these correlations will be further examined following this section.

P-BOMS VERSUS PT (ASSESSED BETWEEN 0 TO 59°/S).

One study (Bryant et al., 2008b) evaluated PT between 0 to 59°/s versus P-BOM (Cincinnati) in the knee flexors of ACLD individuals (FIGURE 31). Within 0 to 59°/s angle-specific measurements/ranges, the following correlation coefficients were found at 10-20°/s (r = 00.80, p= 0.003, n= 27), 20-30°/s (r = 0.70, p= 0.017, n= 27), 30-40°/s (r = 0.74, p= 0.017, n= 27), 40-50°/s (r = 0.78, p= 0.011, n= 27), and 50-60°/s (r = 0.66, p= 0.038, n= 27); suggesting a positive moderate to high correlations between the Cincinnati and PT at 0 to 59°/s for the knee flexors.

P-BOMS VERSUS PT (ASSESSED BETWEEN 60 TO 119°/S).

Three studies (Li et al., 1996; Harilainen et al., 1995; Bryant et al., 2008b) evaluated PT between 60 to 119°/s versus P-BOM (Cincinnati and Lysholm) in the knee flexors of ACLD/ACLR individuals (FIGURE 31). Within 60 to 119°/s angle-specific measurements/ranges, six correlation coefficients were found to be significant ($p < 0.05$).



Significant correlations (p< 0.05) for P-BOMs (Tegner, Cincinnati, Lysholm, POPF, SARS, and FAS) versus peak measurements of peak torque (PT) evaluated by dynamometry in the knee flexors with ACLD and ACLR individuals.

P-BOMS VERSUS PT (ASSESSED BETWEEN 0 TO 59°/s).

One study (Bryant et al., 2008b) evaluated PT between 0 to 59°/s versus P-BOM (Cincinnati) in the knee flexors of ACLD individuals (FIGURE 31). Within 0 to 59°/s angle-specific measurements/ranges, the following correlation coefficients were found at 10-20°/s ($r = 00.80$, $p = 0.003$, $n = 27$), 20-30°/s ($r = 0.70$, $p = 0.017$, $n = 27$), 30-40°/s ($r = 0.74$, $p = 0.017$, $n = 27$), 40-50°/s ($r = 0.78$, $p = 0.011$, $n = 27$), and 50-60°/s ($r = 0.66$, $p = 0.038$, $n = 27$); suggesting a positive moderate to high correlations between the Cincinnati and PT at 0 to 59°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS PT (ASSESSED BETWEEN 60 TO 119°/s).

Three studies (Li et al., 1996; Harilainen et al., 1995; Bryant et al., 2008b) evaluated PT between 60 to 119°/s versus P-BOM (Cincinnati and Lysholm) in the knee flexors of ACLD/ACLR individuals (FIGURE 31). Within 60 to 119°/s angle-specific measurements/ranges, six correlation coefficients were found to be significant ($p < 0.5$).

In the first study (Li et al., 1996), three correlations evaluated PT at 60°/s with Cincinnati with ACLD individuals ($r = 0.45$, $p < 0.001$, $n = 46$; $r = 0.41$, $p < 0.01$, $n = 46$; $r = 0.40$, $p < 0.01$, $n = 46$); suggesting a positive low correlation between the Cincinnati versus PT at 60°/s with the knee flexors of ACLR individuals (TABLE 6; p. 126).

In the second study (Bryant et al., 2008a), two correlation coefficients were found to be significant ($p < 0.5$) evaluating Cincinnati and PT at 60-70°/s ($r = 0.59$, $p < 0.048$, $n = 27$) and 70-80°/s ($r = 0.59$, $p < 0.015$, $n = 27$); suggesting a positive moderate correlation was found between the Cincinnati versus PT at between 60-80°/s in the knee flexors of ACLD individuals (TABLE 6; p. 126).

In the final study (Harilainen et al., 1995), one correlation coefficients was found to be significant ($p < 0.5$) in evaluating Lysholm and PT at 60°/s ($r = 0.21$, $p < 0.04$, $n = 167$; suggesting none or weakly negligible positive correlation between the Cincinnati versus PT at 60°/s in the knee flexors of ACLD individuals (TABLE 6; p. 126).

P-BOMS VERSUS PT (ASSESSED BETWEEN 120 TO 179°/s).

Two studies (Seto et al., 1988; Harter et al., 1988) evaluated PT between 120 to 179°/s versus P-BOMs (FAS, POPF and ARS) in the knee flexors of ACLD/ACLR individuals (FIGURE 31). Within 120 to 179°/s angle-specific measurement/ranges, three correlation coefficients were found to be significant ($p < 0.5$) at 120°/s for the FAS ($r = 0.79$, $p < 0.01$, $n = 25$), ARS ($r = 0.26$, $p = 0.05$, $n = 51$), and POPF ($r = 0.38$, $p < 0.005$, $n = 51$); suggesting a positive high correlation was found between the FAS versus PT at 120°/s, while a lower correlation was found for the POPF ($r = 0.38$) suggesting a low relationship between PT at 120°/s. Finally, results suggest no concomitant relationships were found concurrently between ARS versus PT at 120°/s (TABLE 6; p. 126).

P-BOMS VERSUS PT (ASSESSED BETWEEN 180 TO 239°/s).

Two studies (Li et al., 1996; Baltaci et al., 2012) evaluated PT between 180 to 239°/s versus P-BOMs (Tegner and Cincinnati) in the knee flexors of ACLD individuals (FIGURE 31). Within 180 to 239°/s angle-specific measurements/ranges, three correlation coefficients were found to be significant ($p < 0.5$) at 180°/s for the Tegner ($r_s = 0.52$, $p < 0.05$, $n = 15$) and Cincinnati ($r = 0.46$, $p < 0.001$, $n = 46$; $r = 0.42$, $p < 0.01$, $n = 46$); suggesting a positive low to moderate correlation found between the P-BOMs versus PT at 180°/s (TABLE 6; p. 126).

P-BOMS VERSUS PT (ASSESSED BETWEEN 240 TO 299°/s).

One study (Seto et al., 1988) evaluated PT between 240 to 299°/s versus P-BOM (FAS) in the knee flexors with ACLR individuals (FIGURE 31). Within 240 to 299°/s angle-specific measurements/ranges, the one study following correlation coefficients was found at 240°/s ($r = 0.74$, $p = 0.05$, $n = 25$); suggesting positive high correlations between the FAS and PT at 240°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS PT (ASSESSED 300°/s PLUS).

No reported correlations were found between PT with any angular-specific measurements versus P-BOMs.

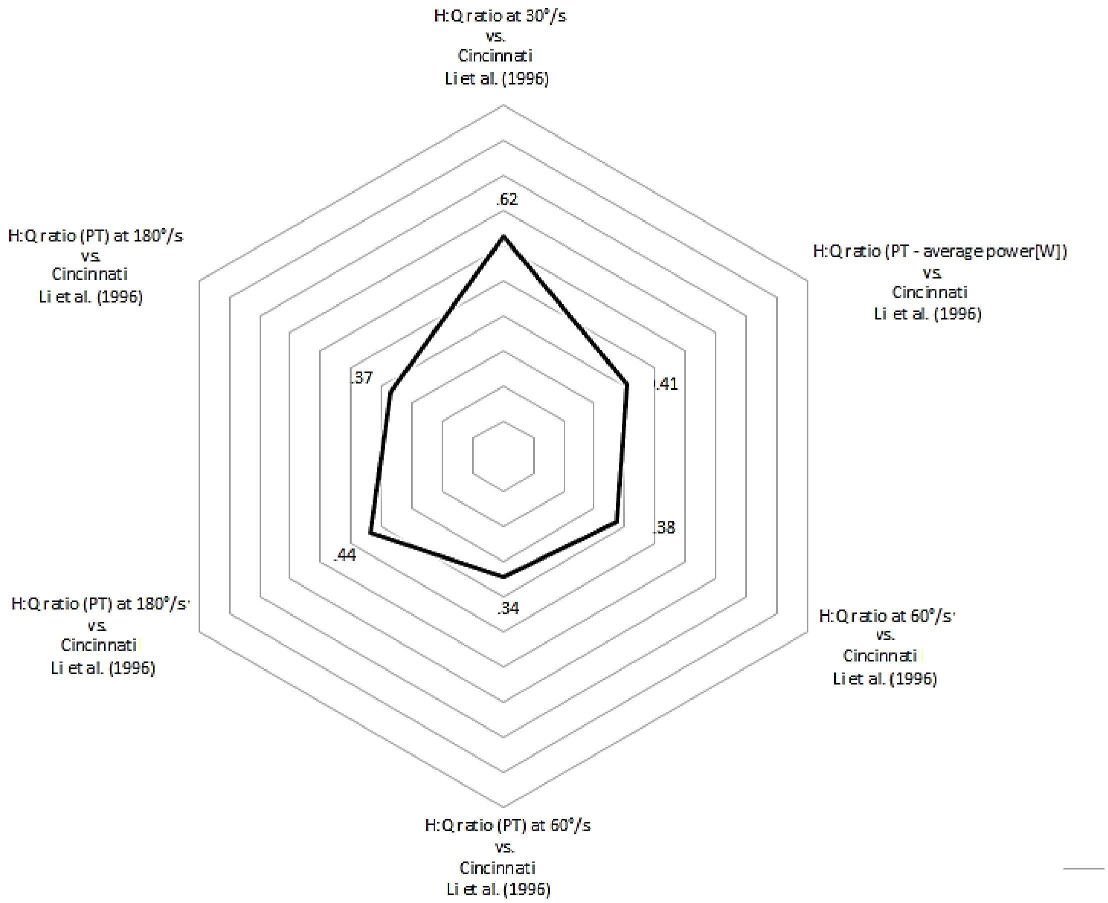
P-BOMS VERSUS PT (ASSESSED AT MULTIPLE PT PARAMETERS).

One study (Kannus et al., 1988) evaluated PT between multiple angular-specific measurements with a rest between (i.e., 60°/sec; post 1-min rest; 180°/sec) versus P-BOM (Lysholm) in the knee extensors of ACLD individuals (FIGURE 31). At this testing parameter (as above), two correlation coefficients were found to be significant ($p < 0.5$) for the Lysholm P-BOM: $r = 0.76$ ($p < 0.001$; $n = 36$) and $rs = 0.78$ ($p < 0.001$; $n = 36$); suggesting a positive height correlation between the Lysholm and PT at multiple testing parameters for the knee extensors (TABLE 6; p. 126).

P-BOMS VERSUS PT (H:Q RATIO).

Two studies reported to evaluate H:Q ratio of the knee flexors and knee extensors PT measurement ratios versus P-BOMs (Cincinnati and IAKS) in ACLD individuals (Li et al., 1996; Lephart et al., 1992).

From these two studies, nine correlations were reported when comparing dynamometry (H:Q) versus P-BOMs



Significant correlations ($p < 0.05$) for P-BOMs (Cincinnati and IAKS) versus peak measurements of H:Q ratio evaluated by dynamometry with ACLD individuals.

From these nine correlations, six correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: H:Q) versus P-BOMs are discussed separately with each angular-specific measurements/ranges. In addition, several studies examined the relationship between PT with knee flexors and knee extensors ratios (i.e., H:Q ratio); these correlations will be further examined following this section.

P-BOMS VERSUS PT (H:Q RATIO ASSESSED BETWEEN 0 TO 59°/s).

One study (Li et al., 1996) evaluated H:Q ratio between 0 to 59°/s versus P-BOM (Cincinnati) in the ACLD individuals. Within 0 to 59°/s angle-specific measurements/ranges, the following correlation coefficients were found at PT at 30°/s ($r = 0.62$, $p = 0.01$, $n = 46$); suggesting positive moderate correlations between the Cincinnati and H:Q ratio at 30°/s (TABLE 6; p. 126).

P-BOMS VERSUS PT (H:Q RATIO ASSESSED BETWEEN 60 TO 119°/s).

Two studies (Li et al., 1996; Lephart et al., 1992) evaluated H:Q ratio between 60 to 119°/s versus P-BOM (Cincinnati and IAKS) in ACLD individuals. Within 60 to 119°/s angle-specific measurement/ranges, three correlation coefficients were found to be significant ($p < 0.5$).

In the only study with significant correlations (Li et al., 1996), three correlations evaluated H:Q ratio at 60°/s versus Cincinnati with ACLD individuals ($r = 0.41$, $p < 0.01$, $n = 46$; $r = 0.38$, $p < 0.01$, $n = 46$; $r = 0.34$, $p < 0.01$, $n = 46$); suggesting a positive low correlation between the Cincinnati versus H:Q ratio at 60°/s (TABLE 6; p. 126). Finally, results suggest no concomitant relationships were found concurrently between IAKS versus H:Q ratio between PT at 60°/s angle-specific measurement/ranges (Lephart et al., 1992) (TABLE 6; p. 126).

P-BOMS VERSUS PT (H:Q RATIO ASSESSED BETWEEN 120 TO 179°/s).

No reported correlation was found between H:Q with any angular-specific measurements (120 to 179°/s) versus P-BOMs.

P-BOMS VERSUS PT (H:Q RATIO ASSESSED BETWEEN 180 TO 239°/s).

One study (Li et al., 1996) evaluated H:Q ratio between 180 to 239°/s versus P-BOM (Cincinnati) in ACLD individuals. Within 180 to 239°/s angle-specific measurement/ranges, three correlation coefficients were found to be significant ($p < 0.5$). In the only study with significant correlations (Li et al., 1996), three correlations evaluated H:Q (PT) ratio at 60°/s versus Cincinnati ($r = 0.41$; $r = 0.38$; $r = 0.34$ [$p < 0.01$, $n = 46$]) with ACLD individuals; suggesting a positive low correlation between the Cincinnati versus H:Q ratio at 60°/s (TABLE 6; p. 126).

P-BOMS VERSUS PT (H:Q RATIO ASSESSED BETWEEN 240 TO 299°/s).

No reported correlation was found to be significant ($p < 0.05$) between H:Q with any angular-specific measurements (240 to 299°/s) versus P-BOMs.

P-BOMS VERSUS PT (H:Q RATIO ASSESSED 300°/s PLUS).

No reported correlation was found to be significant ($p < 0.05$) between H:Q with any angular-specific measurements (300°/s plus) versus P-BOMs.

P-BOMS VERSUS TOTAL WORK (TW):

Four studies reported using peak measurements of total work (TW) assessed by dynamometry to evaluate lower limb total work muscle strength versus P-BOMs (Cincinnati, Lysholm, KFR, ARS, 10PT, and POPF) (Harter et al., 1988; Holm et al., 2000; Kannus, 1988; Risberg et al., 1999c) for the knee flexors ($n = 19$) and knee extensors ($n = 18$). From these four studies, 37 correlations were reported when comparing dynamometry (TW) versus P-BOMs for the knee extensors and flexors, of ACLD/ACLR individuals, respectively. From these 37 correlations, seven correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: TW) versus P-BOMs are discussed separately with each angular-specific measurements/ranges for the knee extensors and knee flexors, respectively.

KNEE FLEXORS:

Four studies reported to evaluate TW (dynamometry) versus P-BOMs (Cincinnati, Lysholm, KFR, KFR, ARS, PT, and POPF) in ACLD/ACLR individuals with the knee flexors (Holm et al., 2000; Harter et al., 1988; Kannus, 1988; Risberg et al., 1999c). From these four studies, 19 correlations were reported comparing dynamometry (TW) versus P-BOMs (as above). From these 19 correlations, three correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: TW) versus P-BOMs are discussed separately with each angular-specific measurements/ranges.

P-BOMS VERSUS TW (ASSESSED BETWEEN 0 TO 59°/s).

No reported correlations were found between TW with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED BETWEEN 60 TO 119°/s).

One study (Kannus, 1988) evaluated TW between 60 to 119°/s versus P-BOM (Lysholm) in the knee flexors with ACLD individuals. Within 60 to 119°/s angle-specific measurement/ranges, the following correlation coefficients were found at 60°/s (r = 0.75, p= 0.001, n= 36; rs= 0.76, p= 0.001, n= 36); suggesting positive high correlations between the Lysholm and TW at 60°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS TW (ASSESSED BETWEEN 120 TO 179°/s).

No reported correlations were found between TW with angular-specific measurement (120 to 179°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED BETWEEN 180 TO 239°/s).

One study (Harter et al., 1988) evaluated TW between 180 to 239°/s versus P-BOM (POPF) in the knee flexors with ACLR individuals (n = 51). Within 180 to 239°/s angle-specific measurements/ranges, the following correlation coefficient was found at 180°/s (r = 0.33, p= 0.01, n= 51); suggesting positive low correlations between the POPF and TW at 180°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS TW (ASSESSED BETWEEN 240 TO 299°/s).

No reported correlations were found between TW with angular-specific measurement (240 to 299°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED 300°/s PLUS).

No reported correlations were found between TW with angular-specific measurement (300°/s plus) versus any P-BOMs.

KNEE EXTENSORS:

Four studies reported to evaluate TW (dynamometry) versus P-BOMs (Cincinnati, Lysholm, KFR, KFR, ARS, PT, and POPF) in ACLD/ACLR individuals with the knee extensors (Holm et al., 2000; Harter et al., 1988; Kannus, 1988; Risberg et al., 1999c). From these four studies, 18 correlations were reported when comparing dynamometry (TW) versus P-BOMs. From these 18 correlations, three correlation coefficient values were significant ($p < 0.05$). Each reported correlation between C-BOMs (dynamometry: TW) versus P-BOMs are discussed separately with each angular-specific measurements/ranges.

P-BOMS VERSUS TW (ASSESSED BETWEEN 0 TO 59°/s).

No reported correlations were found between TW with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED BETWEEN 60 TO 119°/s).

One study (Kannus, 1988) evaluated TW between 60 to 119°/s versus P-BOM (Lysholm) in the knee extensors with ACLD individuals (n = 36). Within 60 to 119°/s angle-specific measurements/ranges, the following correlation coefficients was found at 60°/s (r = 0.82, p= 0.001, n= 36; rs= 0.84, p= 0.001, n= 36); suggesting positive high correlations between the Lysholm and TW at 60°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS TW (ASSESSED BETWEEN 120 TO 179°/s).

No reported correlations were found between TW with angular-specific measurement (120 to 179°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED BETWEEN 180 TO 239°/s).

One study (Harter et al., 1988) evaluated TW between 180 to 239°/s versus P-BOMs (POPF and ARS) in the knee extensors with ACLR individuals ($n = 51$). Within 180 to 239°/s angle-specific measurements/ranges, the following correlation coefficients was found at 180°/s (ARS: $r = 0.31$, $p= 0.02$, $n= 51$; POPF: $r = 0.28$, $p= 0.03$, $n= 51$). These correlations suggest a positive low correlation between the ARS and TW at 180°/s for the knee extensors, and no or negligible correlation for the POPF and TW at 180°/s for the knee extensors (TABLE 6; p. 126).

P-BOMS VERSUS TW (ASSESSED BETWEEN 240 TO 299°/s).

No reported correlations were found between TW with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS TW (ASSESSED 300°/s PLUS).

No reported correlations were found between TW with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION AND DECELERATIONS PHASES AT ANGLE-SPECIFIC MEASUREMENT/RANGES:

Two studies (Lephart et al., 1992; Wilk et al., 1994) reported to assess measurements of acceleration and deceleration phases assessed by dynamometry versus P-BOMs (Noyes (modified) and IAKS). From these two studies, 16 correlations were reported when comparing dynamometry acceleration phases associated with knee flexors and extensors, respectively. In addition, the deceleration phases were additionally associated with knee flexors and extensors, respectively, versus P-BOMs (as above) with ACLR/ACLD individuals. From these 16 correlations, 3 correlation coefficient values were significant ($p< 0.05$). Each reported correlation between C-BOMs (dynamometry: Acceleration and deceleration phases) versus P-BOMs are discussed separately for knee flexors and knee extensors.

ACCELERATION PHASE:

Two studies (Lephart et al., 1992; Wilk et al., 1994) reported to assess measurements of acceleration phases assessed by dynamometry versus P-BOMs (Noyes (modified) and IAKS). From these two studies, 10 correlations were reported when comparing dynamometry acceleration phases for the knee flexors ($n = 5$) and knee extensors ($n = 5$) versus P-BOMs (as above) with ACLR individuals. From these 10 correlations, 3 correlation coefficient values were significant ($p< 0.05$) for knee flexors ($n = 1$) and knee extensors ($n = 2$). Each reported correlation between C-BOMs (dynamometry: acceleration phases) versus P-BOMs are discussed separately for knee flexors and knee extensors.

FLEXORS:

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 0 TO 59°/s).

No reported correlations were found between acceleration phases with the knee flexors with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 60 TO 119°/s).

No significant correlations were found between acceleration phases with the knee flexors with angular-specific measurement (60 to 119°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 120 TO 179°/s).

No reported correlations were found between acceleration phases with the knee flexors with angular-specific measurement (120 to 179°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 180 TO 239°/s).
One study (Wilk et al., 1994) evaluated acceleration phase between 180 to 239°/s versus P-BOM (Noyes modified) in the knee flexors with ACLR individuals. Within 180 to 239°/s angle-specific measurement/ranges, the following correlation coefficient was found at 180°/s ($r = 0.32$, $p = 0.02$, $n = 50$); suggesting positive low correlations between the Noyes (modified) and acceleration phase at 180°/s for the knee flexors (TABLE 6; p. 126).

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 240 TO 299°/s).
No significant correlations were found between acceleration phases with the knee flexors with angular-specific measurement (240 to 299°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 300°/s PLUS).
No significant correlations were found between acceleration phases with the knee flexors with angular-specific measurement (300°/s plus) versus any P-BOMs.

EXTENSORS:

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 0 TO 59°/s).
No reported correlations were found between acceleration phases with the knee extensors with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 60 TO 119°/s).
No significant correlations were found between acceleration phases with the knee extensors with angular-specific measurement (60 to 119°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 120 TO 179°/s).
No reported correlations were found between acceleration phases with the knee extensors with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 180 TO 239°/s).
One study (Wilk et al., 1994) evaluated acceleration phase between 180 to 239°/s versus P-BOM (Noyes modified) in the knee extensors with ACLR individuals. Within 180 to 239°/s angle-specific measurements/ranges, the following correlation coefficient was found at 180°/s ($r = 0.67$, $p = 0.0001$, $n = 50$); suggesting positive moderate correlations between the Noyes (modified) and acceleration phase at 180°/s for the knee extensors (TABLE 6; p. 126).

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 240 TO 299°/s).
No significant correlations were found between acceleration phases with the knee extensors with angular-specific measurement (240 to 299°/s) versus any P-BOMs.

P-BOMS VERSUS ACCELERATION (ASSESSED BETWEEN 300°/s PLUS).
One study (Wilk et al., 1994) evaluated acceleration phase 300°/s plus versus P-BOM (Noyes modified) in the knee extensors with ACLR individuals. Within this and over these angle-specific measurements/ranges, the following correlation coefficient, found at 300°/s, was found to be significant ($r = 0.59$, $p = 0.0001$, $n = 50$); suggesting a positive moderate correlation between the Noyes (modified) and acceleration phase at 180°/s for the knee extensors (TABLE 6; p. 126). One more correlation was found within these measurements/ranges, however, there was a non-significant correlation between acceleration phase at 450°/s with the knee extensors versus Noyes (modified) ($r = 0.16$; $p = 0.31$, $n = 50$).

DECELERATION PHASE:
One study (Wilk et al., 1994) reported to assess measurements of deceleration phases assessed by dynamometry versus P-BOMs (Noyes (modified)). From this one study, 6 correlations were reported when comparing dynamometry deceleration phases for the knee flexors ($n = 3$) and knee

extensors (n = 3) versus P-BOMs (as above) with ACLR individuals. From these 6 correlations, no significant correlation coefficients were found ($p < 0.05$).

FLEXORS:

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 0 TO 59°/s).
No significant correlations were found between deceleration phases with the knee flexors with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 60 TO 119°/s).
No significant correlations were found between deceleration phases with the knee flexors with angular-specific measurement (60 to 119°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 120 TO 179°/s).
No significant correlations were found between deceleration phases with the knee flexors with angular-specific measurement (120 to 179°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 180 TO 239°/s).
No significant correlations were found between deceleration phases with the knee flexor with angular-specific measurement (180 to 239°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 240 TO 299°/s).
No significant correlations were found between deceleration phases with the knee flexors with angular-specific measurement (240 to 299°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 300°/s PLUS).
No significant correlations were found between deceleration phases with the knee flexors with angular-specific measurement (300°/s plus) versus any P-BOMs.
3.6.3.1.8.5.2.2. -EXTENSORS:

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 0 TO 59°/s).
No reported correlations were found between deceleration phases with the knee extensors with angular-specific measurement (0 to 59°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 60 TO 119°/s).
No reported correlations were found between deceleration phases with the knee extensors with angular-specific measurement (60 to 119°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 120 TO 179°/s).
No reported correlations were found between deceleration phases with the knee extensors with angular-specific measurement (120 to 179°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 180 TO 239°/s).
No significant correlations were found between deceleration phases with the knee extensors with angular-specific measurement (180 to 239°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED BETWEEN 240 TO 299°/s).
No reported correlations were found between deceleration phases with the knee extensors with angular-specific measurement (240 to 299°/s) versus any P-BOMs.

P-BOMS VERSUS DECELERATION (ASSESSED 300°/s PLUS).
No significant correlations were found between deceleration phases with the knee extensors with angular-specific measurement (300°/s plus) versus any P-BOMs.

P-BOMS VERSUS DYNAMOMETRY NEUROMUSCULAR TESTS/OUTCOMES:

Two studies (Gleeson et al., 2008; Yates et al., 2016 [under review]) reported to assess neuromuscular outcome measures of knee performance tests/outcomes (i.e., EMD and RFD) evaluated by secondary analysis of PF test/outcome data. From these two studies, eight correlations were reported when comparing neuromuscular performance outcomes versus P-BOMs (Performance Profile and Bi-POMs for the knee flexors and knee extensors. From these eight correlations, four correlation coefficient values were significant ($p < 0.05$) for the knee flexors only. Each reported correlation between C-BOMs (dynamometry: neuromuscular outcomes) versus P-BOMs are discussed.

P-BOMS VERSUS ELECTROMECHANICAL DELAY (EMD).

The first correlation was found between EMD versus Bi-POMs at 8 weeks post-surgery ($r_s = 0.77$, $p < 0.05$, $n = 9$) (Gleeson et al., 2008); suggesting a positive high correlation between Bi-POMs and EMD for the knee flexors with ACLR individuals. Similarly, within the same study, a four correlations case was found between EMD versus Performance Profile at pre-surgery, 8 weeks and 10 weeks post-surgery, respectively ($r_s = -0.82$; $p < 0.05$, $n = 9$; $r_s = -0.81$; $p < 0.05$, $n = 9$; $r_s = -0.84$; $p < 0.05$, $n = 9$); suggesting positive high correlations between Performance Profile and EMD for the knee flexors with ACLR individuals (TABLE 6; p. 126).

P-BOMS VERSUS RATE OF FORCE DEVELOPMENT (RFD).

No significant correlations were found concurrently between RFD versus any P-BOMs.

APPENDIX 7

All correlation coefficient values for all Patient-Based Outcome Measures (P-BOMs) and Clinician-Based Outcome Measures (C-BOMs) evaluated concomitantly (n = 388).

TABLE 74 - Correlation coefficient values for P-BOMs versus triple-hop test for distance.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	Single-leg-triple-hop test for distance				
Baltaci et al., (2012)	ACLR (n = 15)	Lysholm	rs	**0.55**	**p< 0.05**
Baltaci et al., (2012)	ACLR (n = 15)	Tegner	rs	0.08	ns
Holm et al., (2000)	ACLR (n = 151)	Cincinnati (6 months)	r	0.31	ns
Holm et al., (2000)	ACLR (n = 151)	Cincinnati (12 months)	r	0.27	ns
Holm et al., (2000)	ACLR (n = 151)	Cincinnati (24 months)	r	0.34	ns
Reinke et al., (2011)	ACLR (n = 69)	IKDC (hop-test)	rs	**0.40**	**p< 0.001**
Reinke et al., (2011)	ACLR (n = 69)	KOOS (sport)	rs	**0.20**	**p< 0.05**
Reinke et al., (2011)	ACLR (n = 69)	KOOS (QoL)	rs	**0.30**	**p< 0.01**
Reinke et al., (2011)	ACLR (n = 69)	MARX	rs	0.20	ns

TABLE 75 - Correlation coefficient values for P-BOMs versus single-leg-triple-crossover-hop-test for distance.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	Single-leg-triple-crossover-hop for distance				
Baltaci et al., (2012)	ACLR (n = 15)	Lysholm	rs	**0.66**	**p< 0.05**
Baltaci et al., (2012)	ACLR (n = 15)	Tegner	rs	0.28	ns
Goh et al., (1997)	ACLR (n = 20)	Noyes (modified)	r	0.44	ns
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified)	r	**0.38**	**p< 0.05**
Goh et al., (1997)	ACLR (n = 20)	Knee satisfaction	r	**0.50**	**p< 0.05**
Reinke et al., (2011)	ACLR (n = 69)	IKDC (hop-test)	rs	0.20	p= 0.23
Reinke et al., (2011)	ACLR (n = 69)	KOOS (sport)	rs	0.20	p= 0.07
Reinke et al., (2011)	ACLR (n = 69)	KOOS (QoL)	rs	0.10	p= 0.42
Reinke et al., (2011)	ACLR (n = 69)	MARX	rs	-0.10	p= 0.60

TABLE 76 - Correlation coefficient values for P-BOMs versus vertical-jump tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	Vertical-jump tests				
Baltaci et al., (2012)	ACLR (n = 15)	Lysholm	rs	0.08	ns
Baltaci et al., (2012)	ACLR (n = 15)	Tegner	rs	0.15	ns
Bryant et al., (2008b)	ACLR (n = 13)	Cincinnati/LLMS	r	**-0.55**	**p= 0.041**

TABLE 77 - Correlation coefficient values for P-BOMs versus 6m, 10, and 12m single-leg-hop test for timed distances.

	Subjects	**P-BOMs**	**Correlation coefficient**	**Correlation coefficient value**	**Level of significance**
	6m-timed-single-leg-hop test:				
Goh et al., (1997)	ACLR (n = 20)	Noyes (modified)	r	**0.62**	**p< 0.05**
Goh et al., (1997)	ACLR (n = 20)	Knee satisfaction	r	**0.72**	**p< 0.05**
Reinke et al., (2011)	ACLR (n = 69)	IKDC (hop-test)	rs	**-0.30**	**p= 0.03**
Reinke et al., (2011)	ACLR (n = 69)	KOOS (sport)	rs	-0.20	p= 0.11
Reinke et al., (2011)	ACLR (n = 69)	KOOS (QoL)	rs	-0.20	p= 0.08
Reinke et al., (2011)	ACLR (n = 69)	MARX	rs	-0.20	p= 0.14
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified)	r	**0.31**	**p< 0.05**
	10m-timed-single-leg-hop test:				
Neeb et al., (1997)	ACLR (n = 30)	SARS	τ	**-0.22**	**p< 0.05**
Neeb et al., (1997)	ACLR (n = 30)	FORSS	τ	0.05	ns
Neeb et al., (1997)	ACLR (n = 30)	Lysholm	τ	-0.09	ns
Neeb et al., (1997)	ACLR (n = 30)	Tegner	τ	**-0.31**	**p< 0.05**
	12m-time-single-leg-hop test:				
Goh et al., (1997)	ACLR (n = 20)	Noyes (modified)	r	**0.56**	**p< 0.05**
Goh et al., (1997)	ACLR (n = 20)	Knee satisfaction	r	**0.57**	**p< 0.05**

TABLE 78 - Correlation coefficient values for P-BOMs versus timed stair/step/ladder-hop tests.

	Subjects	P-BOMs	Correlation Coefficient	Correlation Coefficient Value	Level of significance
	Stair-hopple-test (timed):				
Goh et al., (1997)	ACLR (n = 20)	Noyes (modified)	r	**0.75**	**$p < 0.05$**
Goh et al., (1997)	ACLR (n = 20)	Knee satisfaction	r	**0.69**	**$p < 0.05$**
	Ladder-hop-test (timed):				
Baltaci et al., (2013)	ACLR (n = 15)	Lysholm	rs	**0.62**	**$p < 0.05$**
Baltaci et al., (2013)	ACLR (n = 15)	Tegner	rs	0.37	not stated

TABLE 79 - Correlation coefficient values for P-BOMs versus timed-agility tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	Carioca test (timed) over 12m distance:				
Kong et al., (2012)	ACLR (n = 30)	Lysholm	r	-0.058	p= 0.761
Kong et al., (2012)	ACLR (n = 30)	IKDC	r	**-0.453**	**p= 0.012**
Kong et al., (2012)	ACLR (n = 30)	Tegner	r	**-0.484**	**p= 0.007**
	Co-contraction test (timed):				
Kong et al., (2012)	ACLR (n = 30)	Lysholm	r	-0.057	p= 0.763
Kong et al., (2012)	ACLR (n = 30)	IKDC	r	**-0.569**	**p= 0.001**
Kong et al., (2012)	ACLR (n = 30)	Tegner	r	**-0.397**	**p= 0.030**
	Shuttle-run-test (timed):				
Baltaci et al., (2013)	ACLR (n = 15)	Lysholm (total 12m)	rs	0.02	not state
Baltaci et al., (2013)	ACLR (n = 15)	Tegner (total 12m)	rs	**0.57**	**p< 0.05**
Kong et al., (2012)	ACLR (n = 30)	Lysholm (total 24.4m)	r	-0.19	P= 0.312
Kong et al., (2012)	ACLR (n = 30)	IKDC (total 24.4m)	r	**-0.50**	**p= 0.004**
Kong et al., (2012)	ACLR (n = 30)	Tegner (total 24.4m)	r	**-0.51**	**p= 0.004**
	Stairs-step-test (timed):				
Baltaci et al., (2012)	ACLR (n = 15)	Lysholm	rs	0.25	not stated
Baltaci et al., (2012)	ACLR (n = 15)	Tegner	rs	0.70	not stated

TABLE 80 - Correlation coefficient values for P-BOMs versus KT-1000.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	KT-1000 assessment for knee stability:				
Chia a Chok, (1999)	ACLR (n = 21)	IKDC (activity) (3-months)	τ	.026	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (3-months)	τ	**0.410**	**p< 0.05**
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop) (3-months)	τ	**0.515**	**p< 0.01**
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (activity level) (6-months)	τ	-0.031	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (6-months)	τ	-0.135	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop) (6-months)	τ	0.239	ns
Harter et al., (1988)	ACLR (n = 51)	KFR (at 90N)	r	-0.02	p= 0.45
Harter et al., (1988)	ACLR (n = 51)	POPF (at 90N)	r	**-0.31**	**p= 0.01**
Harter et al., (1988)	ACLR (n = 51)	ARS (at 90N)	r	-0.16	p= 0.13
Harter et al., (1988)	ACLR (n = 51)	10PT (at 90N)	r	-0.12	p= 0.20
Hrubesch et al., (2000)	ACLR (n = 44)	IKDC	rs	0.319	ns
Hrubesch et al., (2000)	ACLR (n = 44)	Lysholm	rs	0.146	ns
Hrubesch et al., (2000)	ACLR (n = 44)	Cincinnati	rs	0.426	ns
Hrubesch et al., (2000)	ACLR (n = 44)	Marshall	rs	0.363	ns
Hrubesch et al., (2000)	ACLR (n = 44)	OAK	rs	0.319	ns
Hrubesch et al., (2000)	ACLR (n = 44)	Zarins & Rowe	rs	0.41	ns
Hrubesch et al., (2000)	ACLR (n = 44)	Feagin & Blake	rs	0.53	ns
Kocher et al., (2004)[1]	ACLR (n = 202)	Satisfaction	rs	0.05	p= 0.52
Kocher et al., (2004)[1]	ACLR (n = 202)	Sport level	rs	-0.05	p= 0.48
Kocher et al., (2004)[1]	ACLR (n = 202)	ADL level	rs	-0.02	p= 0.75
Kocher et al., (2004)[1]	ACLR (n = 202)	Work level	rs	-0.01	p= 0.99
Kocher et al., (2004)[1]	ACLR (n = 202)	Lysholm	rs	-0.04	p= 0.60

Neeb et al., (1997)	ACLR (n = 30)	SARS	τ	0.09	ns
Neeb et al., (1997)	ACLR (n = 30)	FORSS	τ	-0.19	ns
Neeb et al., (1997)	ACLR (n = 30)	Lysholm	τ	-0.03	ns
Neeb et al., (1997)	ACLR (n = 30)	Tegner	τ	0.25	**p< 0.05**
Lephart et al., (1992)	ACLR (n = 41)	IAKS	r	0.14	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC^2 (3 month)	rs	0.72	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC^2 (6 month)	rs	0.83	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC^2 (1 year)	rs	0.85	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC^2 (2 year)	rs	0.82	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (3 months)	r	-0.13	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (6 months)	r	-0.01	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (1 year)	r	0.03	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (2 years)	r	0.09	not stated
Ross et al., (2002)	ACLR (n = 50)	[KOS, ADLS, SAS]	r	-0.01	ns
Tyler et al., (1999)	ACLR (n = 90)	Lysholm (89N)	r	-0.09	p= 0.42
Tyler et al., (1999)	ACLR (n = 90)	Tegner (89N)	r	0.02	p= 0.90
Sernert el al., (1999)	ACLR (n = 527)	Tegner (total, 89N)	rs	-0.06	not stated
Sernert el al., (1999)	ACLR (n = 527)	Tegner (anterior, 89N)	rs	0.06	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (total) (anterior, 89N)	rs	-0.17	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (Pain) (anterior,89N)	rs	-0.12	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (instab.) (anterior,89N)	rs	-0.21	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (total) (total, 89N)	rs	-0.16	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (Pain) (total, 89N)	rs	-0.11	not stated
Sernert el al., (1999)	ACLR (n = 527)	Lysholm (instab.) (total, 89N)	rs	0.20	not stated

Sernert el al., (1999)	ACLR (n = 527)	IKDC (anterior, 89N)	rs	-0.35	not stated
Sernert el al., (1999)	ACLR (n = 527)	IKDC (total, 89N)	rs	-0.34	not stated
Sernert el al., (1999)	ACLR (n = 527)	Subj. evaluation (anterior, 89N)	rs	-0.18	not stated
Sernert el al., (1999)	ACLR (n = 527)	Subj. evaluation (total, 89N)	rs	-0.17	not stated
Sernert el al., (1999)	ACLR (n = 527)	Subj. expectation (total, 89N)	rs	-0.20	not stated
Sernert el al., (1999)	ACLR (n = 527)	Subj. expectation (anterior,89N)	rs	-0.20	not stated
Gleeson et al., (2008)[3]	ACLR (n = 9)	Performance Profile (pre-surgery)	rs	0.68	**p< 0.05**
Gleeson et al., (2008)[3]	ACLR (n = 9)	ERAIQ(discouraged) (8 weeks)	rs	0.79	**p< 0.05**
Gleeson et al., (2008)[3]	ACLR (n = 9)	Performance Profile (8 weeks)	rs	0.72	**p< 0.05**
Gleeson et al., (2008)[3]	ACLR (n = 9)	Bi-POMS(tired-energetic) (8 weeks)	r	-0.87	**p< 0.01**
Gleeson et al., (2008)[3]	ACLR (n = 9)	Bi-POMS(depressed-elated) (8 weeks)	r	-0.85	**p< 0.01**
Gleeson et al., (2008)[3]	ACLR (n = 9)	Bi-POMS(hostile-agreeable) (8 weeks)	r	-0.72	**p< 0.05**
Gleeson et al., (2008)[3]	ACLR (n = 9)	Performance Profile (10 weeks)	rs	0.70	**p< 0.05**
Gleeson et al., (2008)[3]	ACLR (n = 9)	ERAIQ (Pain) (10 weeks)	r	0.78	**p< 0.05**
Yates et al., (2016) [under review][3]	ACLR (n = 9)	Performance Profile[4]	rs	0.68	**p< 0.05**

TABLE 81 - Correlation coefficient values for P-BOMs with KT-2000 and CA-4000

KT-2000 assessment for knee stability:

Snyder-Mackler et al., (1997)	ACLD (n = 20)	Lysholm (at 89N)	r	0.005	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	Lysholm (manual. Max.[5])	r	0.033	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	KOS(sports) (at 89N)	r	0.052	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	KOS(sports) (manual. Max.[5])	r	0.078	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	KOS(ADL) (at 89N)	r	-0.058	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	KOS(ADL) (manual. Max.[5])	r	0.138	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	GKS (at 89N)	r	0.243	ns
Snyder-Mackler et al., (1997)	ACLD (n = 20)	GKS (manual. Max.[5])	r	0.134	ns

CA-4000 assessment for knee stability:

Harilainen et al., (1995)	ACLD (n = 167)	Tegner	r	0.1296	ns
Harilainen et al., (1995)	ACLD (n = 167)	Lysholm	r	0.0436	ns

TABLE 82 - Correlation coefficient values for P-BOMs versus pivot-shift-test

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	Pivot-shift assessment for knee stability:				
Neeb et al., (1997)	ACLR (n = 30)	SARS	τ	-0.07	ns
Neeb et al., (1997)	ACLR (n = 30)	FORSS	τ	0.16	ns
Neeb et al., (1997)	ACLR (n = 30)	Lysholm	τ	-0.18	ns
Neeb et al., (1997)	ACLR (n = 30)	Tegner	τ	0.13	ns

TABLE 83 - Correlation coefficient values for P-BOMs versus manual Lachman-tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	Manual Lachman-test assessment for knee stability:				
Neeb et al., (1997)	ACLR (n = 30)	SARS	τ	0.04	ns
Neeb et al., (1997)	ACLR (n = 30)	FORSS	τ	0.04	ns
Neeb et al., (1997)	ACLR (n = 30)	Lysholm	τ	0.01	ns
Neeb et al., (1997)	ACLR (n = 30)	Tegner	τ	0.12	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (extra-art)	r	-0.16	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (intra-art)	r	0.19	ns
Neeb et al., (1997)	ACLR (n = 30)	Tegner	τ	0.12	ns
Sernert et al., (1999)	ACLR (n = 527)	Tegner	rs	-0.06	not stated
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (total)	rs	-0.26	not stated
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (Pain)	rs	-0.19	not stated
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (instab.)	rs	-0.25	not stated
Sernert et al., (1999)	ACLR (n = 527)	IKDC	rs	-0.42	not stated
Sernert et al., (1999)	ACLR (n = 527)	Subj. evaluation	rs	-0.20	not stated
Sernert et al., (1999)	ACLR (n = 527)	Subj. expectation	rs	-0.19	not stated
Harter et al., (1988)	ACLR (n = 51)	KFR	r	-0.05	p= 0.36
Harter et al., (1988)	ACLR (n = 51)	ARS	r	-0.01	p= 0.48
Harter et al., (1988)	ACLR (n = 51)	POPF	r	-0.16	P= 0.13
Harter et al., (1988)	ACLR (n = 51)	10PT	r	0.06	p= 0.34

TABLE 84 - Correlation coefficient values for P-BOMs versus lateral-pivot-shift-test.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	Lateral-pivot-shift test assessment for knee stability:				
Seto et al., (1988)	ACLR (n = 25)	FAS[1]	r	-0.66407	ns
Seto et al., (1988)	ACLR (n = 25)	FAS[2]	r	-0.62532	ns

TABLE 85 - Correlation coefficient values for P-BOMs versus anterior-draw-tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	Anterior-draw test assessment for knee stability:				
Seto et al., (1988)	ACLR (n = 25)	FAS/Anterior drawer (neutral) [1]	r	-0.19625	ns
Seto et al., (1988)	ACLR (n = 25)	FAS/Anterior drawer (neutral) [2]	r	0.24689	ns
Seto et al., (1988)	ACLR (n = 25)	FAS/Anterior drawer 15° external rotation [1]	r	0.12154	ns
Seto et al., (1988)	ACLR (n = 25)	FAS/Anterior drawer 15° external rotation [2]	r	0.39459	ns

[1]= patients underwent extra-articular ACLR
[2]= patients underwent intra-articular ACLR

TABLE 86 - Correlation coefficient values for P-BOMs versus knee ligament tests evaluating varus and valgus measurements.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient	Level of significance
	<u>Knee ligaments tests:</u>				
	Varus:				
Seto et al., (1988)	ACLR (n = 25)	FAS (0° ext.[1])	r	-0.36192	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (30° flex.[1])	r	-0.36563	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (0° ext.[2])	r	-0.14618	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (30° flex.[2])	r	-0.14618	ns
	Valgus:				
Seto et al., (1988)	ACLR (n = 25)	FAS (0° ext.[1])	r	-0.10982	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (30° flex.[1]	r	-0.26481	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (0° ext.[2])	r	.021797	ns
Seto et al., (1988)	ACLR (n = 25)	FAS (30° flex.[2])	r	0.22628	ns

[1]= Patients underwent extra-articular ACLR
[2]= Patients underwent intra-articular ACLR

TABLE 87 - Correlation coefficient values for P-BOMs versus ROM tests for knee flexion and knee extension measurements.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient Value	Level of significance
	<u>ROM knee ligaments tests:</u>				
	<u>Knee flexion:</u>				
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (activity) (3-months)	τ	0.182	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (3-months)	τ	-0.082	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop test) (3-months)	τ	**-0.404**	**p< 0.05**
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (activity) (6-months)	τ	**-0.619**	**p< 0.01**
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (6-months)	τ	-0.167	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop test) (6-months)	τ	-0.373	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (3-months)	r	0.20	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (6-months)	r	0.37	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (1-year)	r	0.23	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (2-year)	r	0.05	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (3-months)	rs	-0.70	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (6-months)	rs	-0.49	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (1-year)	rs	-0.37	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (2-year)	rs	-0.33	ns

	<u>Knee extension:</u>				
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (activity level) (3-months)	τ	-0.147	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (3-months)	τ	-0.076	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop test) (3-months)	τ	**-0.417**	**p< 0.05**
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (activity) (6-months)	τ	0.180	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (Symptoms) (6-months)	τ	-0.122	ns
Chia & Chok, (1999)	ACLR (n = 21)	IKDC (hop test) (6-months)	τ	-0.102	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (3-months)	r	-0.33	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (6-months)	r	-0.26	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (1-year)	r	-0.08	ns
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (2-year)	r	-0.08	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (extension deficit) (3-months)	rs	0.83	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (extension deficit) (6-months)	rs	0.75	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (extension deficit) (1-year)	rs	0.77	ns
Risberg et al., (1999b)	ACLR (n = 120)	IKDC (extension deficit) (2-year)	rs	0.50	ns

TABLE 88 - Correlation coefficient values for P-BOMs versus knee walking test and loss of anterior knee sensitivity tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	Donor-site sensitivity-test 1 - Kneeling and kneel-walking test:				
Sernert et al., (1999)	ACLR (n = 527)	Tegner	rs	0.15	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (total)	rs	0.41	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (Pain)	rs	0.36	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (instability)	rs	0.21	ns
Sernert et al., (1999)	ACLR (n = 527)	IKDC	rs	0.29	ns
Sernert et al., (1999)	ACLR (n = 527)	VAS (Subj. evaluation)	rs	0.39	ns
Sernert et al., (1999)	ACLR (n = 527)	VAS (Subj. expectations)	rs	0.26	ns
	Loss of anterior knee sensitivity:				
Sernert et al., (1999)	ACLR (n = 527)	Tegner	rs	-0.12	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (total)	rs	-0.22	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (Pain)	rs	-0.18	ns
Sernert et al., (1999)	ACLR (n = 527)	Lysholm (instability)	rs	-0.12	ns
Sernert et al., (1999)	ACLR (n = 527)	IKDC	rs	-0.14	ns
Sernert et al., (1999)	ACLR (n = 527)	VAS (Subj. evaluation)	rs	-0.20	ns
Sernert et al., (1999)	ACLR (n = 527)	VAS (Subj. expectations)	rs	-0.08	ns

TABLE 89 - Correlation coefficient values for P-BOMs versus proprioceptive assessments

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	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	TDPM:				
Borsa et al., (1998)	ACLD (n = 29)	Lysholm	r	-0.19	ns
Borsa et al., (1998)	ACLD (n = 29)	Cincinnati	r	-0.34	ns
Risberg et al., (1999a)	ACLR (n = 20)	KOOS (Pain)	r	0.21	ns
Risberg et al., (1999a)	ACLR (n = 20)	KOOS (Symptoms)	r	0.17	ns
Risberg et al., (1999a)	ACLR (n = 20)	KOOS (ADL)	r	0.09	ns
Risberg et al., (1999a)	ACLR (n = 20)	KOOS (sport)	r	0.14	ns
Risberg et al., (1999a)	ACLR (n = 20)	KOOS (QoL)	r	0.33	ns
Risberg et al., (1999a)	ACLR (n = 20)	Cincinnati	r	0.21	ns
	TSP:				
Trulsson et al., (2010)	ACLR (n = 53)	KOOS (sport).	rs	-0.43	**p= 0.001**
	RPP:				
Harter et al., (1988)	ACLR (n = 51)	KFR	r	0.02	p= 0.45
Harter et al., (1988)	ACLR (n = 51)	POPF	r	0.03	p= 0.41
Harter et al., (1988)	ACLR (n = 51)	ARS	r	0.03	p= 0.41
Harter et al., (1988)	ACLR (n = 51)	10PT	r	0.06	p = 0.35
	JPS:				
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.70	**p< 0.05**
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.68	**p< 0.05**

TABLE 90 - Correlation coefficient values for P-BOMs versus assessments of balance tests.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	Static Balance Index (SBI):				
Borsa et al., (1998)	ACLD (n = 29)	Lysholm	r	0.09	ns
Borsa et al., (1998)	ACLD (n = 29)	Cincinnati	r	0.36	ns
	Dynamic Postural Stability:				
Park et al., (2010)	ACLR (n = 40)	Lysholm	rs	-0.49	**p= 0.01**
Park et al., (2010)	ACLR (n = 40)	IKDC	rs	-0.52	**p= 0.05**

TABLE 91 - Correlation coefficient values for P-BOMs versus Peak measurement evaluating Peak Force (PF) with knee flexors and knee extensors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	PF (Knee flexors):				
Borsa et al., (1998)	ACLD (n = 29)	Lysholm (at 60° knee angle)	r	0.24	ns
Borsa et al., (1998)	ACLD (n = 29)	Cincinnati (at 60° knee angle)	r	0.30	ns
Gleeson et al., (2008)	ACLR (n = 9)	Bi-POMS (anxious subscale) (8 weeks post-surgery)	r	0.77	**p< 0.05**
Gleeson et al., (2008)	ACLR (n = 9)	Performance Profile (8 weeks post-surgery)	rs	0.82	**p< 0.01**
Gleeson et al., (2008)	ACLR (n = 9)	Performance Profile (pre-surgery)	rs	0.85	**p< 0.01**
Gleeson et al., (2008)	ACLR (n = 9)	ERAIQ [8 weeks post-surgery)	rs	0.75	**p< 0.05**
Gleeson et al., (2008)	ACLR (n = 9)	Bi-POMS (10 weeks post-surgery)	r	0.74	**p< 0.05**
Yates et al., (2016)	ACLR (n = 9)	Performance Profile (week-8 antecedent scores from week-10)	rs	0.71	**p< 0.05**
Yates et al., (2016)	ACLR (n = 9)	Performance Profile (week-6 antecedent scores from week-8)	rs	0.70	**p< 0.05**
	PF (Knee extensors):				
Yates et al., (2016)	ACLR (n = 9)	Performance Profile (week-8 antecedent scores from week-10)	rs	0.71	**p< 0.05**
Yates et al., (2016)	ACLR (n = 9)	Performance Profile (week-6 antecedent scores from week-8)	rs	0.70	**p< 0.05**

TABLE 92 - Correlation coefficient values for P-BOMs versus assessments of PT of knee extensors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	<u>PEAK MEASUREMENTS: PT (Knee extensors)</u>				
	Peak Torque assessed at (2) knee angle velocity between 0 to 59°/s:				
Bryant et al., (2008a)	ACLR (n =	Cincinnati (20-30°)	r	0.59	p= 0.016
Bryant et al., (2008a)	ACLR (n =	Cincinnati (30-40°)	r	0.56	p= 0.023
Bryant et al., (2008a)	ACLR (n =	Cincinnati (40-50°)	r	0.53	p= 0.030
Bryant et al., (2008a)	ACLR (n =	Cincinnati (50-60°)	r	0.48	p= 0.047
	Peak Torque assessed at (2) knee angle velocity between 60 to 119°/s:				
Bryant et al., (2008a)	ACLR (n =	Cincinnati (60 - 119°/s)	r	0.51	p= 0.037
Bryant et al., (2008b)	ACLR (n =	Cincinnati (70-80°/s)	r	0.40	p= 0.086
Harilainen et al., (1995)	ACLD (n =	Lysholm (60°/s)	r	0.17	p = 0.08
Lephart et al., (1992)	ACLR (n =	IAKS (60°/s)	r	0.15	ns
Ross et al., (2002)	ACLR (n =	[KOS, ADLS, SAS] (60°/s)	r	0.29	ns
	Peak Torque assessed at (2) knee angle velocity between 120 to 179°/s:				
Harter et al., 1988)	ACLR (n =	ARS (120°/s)	r	0.24	p = 0.05
Seto et al., (1988)	ACLR (n =	FAS (120°/s)	r	0.74	p< 0.05
Seto et al., (1988)	ACLR (n =	FAS (120°/s)	r	0.50	ns
Harter et al., (1988)	ACLR (n =	10PT (120°/s)	r	0.17	p = 0.14
Harter et al., (1988)	ACLR (n =	KFR (120°/s)	r	0.24	p = 0.06
Harter et al., (1988)	ACLR (n =	POPF (120°/s)	r	0.15	p = 0.15

	Peak Torque assessed at (2) knee angle velocity between 180 to 239°/s:				
Wilk et al., (1994)	ACLR (n =	Noyes (modified) (180°/s)	r	0.71	p = 0.01
	Peak Torque assessed at (2) knee angle velocity between 240 to 299°/s:				
Lephart et al., (1992)	ACLR (n =	IAKS (270°/s)	r	0.13	ns
Seto et al., (1988)	ACLR (n =	FAS (240°/s)	r	0.50	ns
	Peak Torque assessed at (2) knee angle velocity between 300°/s plus:				
Wilk et al., (1994)	ACLD (n =	Noyes (modified) (300°/s)	r	0.67	p = 0.05
Wilk et al., (1994)	ACLD (n =	Noyes (modified) (450°/s)	r	0.44	p = 0.13
	Peak Torque assessed at (2) assessed at multiple PT parameters:				
Kannus, (1988)	ACLD (n =	Lysholm (60°/s; post 1 min rest; 180°/s)	rs	0.85	p< 0.001
Kannus, (1988)	ACLD (n =	Lysholm (60°/s; post 1 min rest; 180°/s)	r	0.84	p< 0.001

TABLE 93 - Correlation coefficient values for P-BOMs versus assessments of PT of knee flexors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient Value	Level of significance
	<u>PT (Knee flexors):</u>				
	Peak Torque assessed at (2) knee angle velocity between 0 to 59°/s:				
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (10-20°)	r	0.80	p= 0.003
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (40-50°)	r	0.78	p= 0.011
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (40-40°)	r	0.74	p= 0.011
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (20-30°)	r	0.70	p= 0.017
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (50-60°)	r	0.66	p= 0.038
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (50-60°)	r	0.42	p= 0.072
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (60-70°)	r	-0.36	p= 0.098
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (40-50°)	r	-0.27	p= 0.167
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (10-20°)	r	-0.25	p= 0.198
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (30-40°)	r	-0.18	p= 0.260
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (20-30°)	r	-0.11	p= 0.360
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (10-20°)	r	-0.08	p= 0.382
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (20-30°)	r	-0.06	p= 0.481
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (40-50°)	r	-0.01	p= 0.487
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (30-40°)	r	0.007	p= 0.492

	Peak Torque assessed at (2) angle velocity between 60 to 119°/s:				
Bryant et al., (2008a)	ACLD (n = 12)	Cincinnati (60-70°)	r	0.59	p= 0.048
Bryant et al., (2008a)	ACLR (n = 12)	Cincinnati (70-80°)	r	0.58	p= 0.015
Harilainen et al., (1995)	ACLR (n =	Lysholm (60°/s)	r	0.21	p= 0.04
Li et al., 1996)	ACLR (n = 46)	Cincinnati (60°/s)	r	0.45	p< 0.001
Li et al., 1996)	ACLR (n = 46)	Cincinnati (60°/s)	r	0.41	p< 0.01
Li et al., 1996)	ACLR (n = 46)	Cincinnati (60°/s)	r	0.40	p< 0.01
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (60-70°/s)	r	-0.39	p= 0.082
Bryant et al., (2008a)	ACLR (n = 27)	Cincinnati (70-80°/s)	r	0.38	p= 0.095
Bryant et al., (2008a)	ACLR (n =	Cincinnati (60-70°/s)	r	0.37	p= 0.102
Bryant et al., (2008a)	ACLD (n = 27)	Cincinnati (70-80°/s)	r	0.23	p= 0.262
Lephart et al., (1992)	ACLR (n = 41)	IAKS (60°/s)	r	0.17	ns
	Peak Torque assessed at (2) angle velocity between 120 to 179°/s:				
Harter et al., 1988)	ACLR (n = 51)	POPF (120°/s)	r	0.38	p= .0005
Harter et al., 1988)	ACLR (n = 51)	ARS (120°/s)	r	0.26	p= 0.04
Seto et al., (1988)	ACLR (n = 25)	FAS (120°/s)	r	0.79	p< 0.01
Harter et al., (1988)	ACLR (n = 51)	KFR (120°/s)	r	0.11	p= 0.23
Harter et al., (1988)	ACLR (n = 51)	10PT (120°/s)	r	0.07	p= 0.33
Seto et al., (1988)	ACLR (n = 25)	FAS (120°/s)	r	-0.27	Ns
	Peak Torque assessed at (2) angle velocity between 180 to 239°/s:				
Baltaci et al., (2012)	ACLR (n = 15)	Tegner (180°/s)	rs	0.52	p< 0.05
Li et al., 1996)	ACLR (n = 46)	Cincinnati (180°/s)	r	0.46	p< 0.001
Li et al., 1996)	ACLR (n = 46)	Cincinnati (180°/s)	r	0.42	p< 0.01
Wilk et al., (1994)	5 ACLR (n = 0)	Noyes (modified (180°/s)	r	0.18	p= 0.251

	Peak Torque assessed at (2) angle velocity between 240 to 299°/s:				
Seto et al., 1988)	ACLR (n = 25)	FAS (240°/s)	r	0.74	$p < 0.05$
Lephart et al., (1992)	ACLR (n = 41)	IAKS (270°/s)	r	0.09	Ns
Seto et al., (1988)	ACLR (n = 25)	FAS (240°/s)	r	-0.29	Ns
	Peak Torque assessed at (2) angle velocity 300°/s plus:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300°/s)	r	0.67	$p = 0.05$
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (450°/s)	r	0.39	$p = 0.212$
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300°/s)	r	0.27	$p = 0.29$
	Peak Torque assessed at (2) assessed at multiple PT parameters:				
Kannus, (1988)	ACLR (n = 36)	Lysholm (60°/s; post 1-min rest; 180°/s)	rs	0.78	$p < 0.001$
Kannus, (1988)	ACLR (n = 36)	Lysholm (60°/s; post 1-min rest; 180°/s)	r	0.76	$p < 0.001$

TABLE 94 - Correlation coefficient values for P-BOMs versus dynamometry H:Q relationships at various knee velocities.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	H:Q relationship (knee flexors: knee extensors) at various knee velocities:				
	H:Q ratio (assessed between 0 to 59°/s):				
Li et al., (1996)	ACLD (n = 46)	Cincinnati (30°/s)	r	0.62	**p< 0.001**
	H:Q ratio (assessed between 60 to 119°/s):				
Li et al., (1996)	ACLD (n =	Cincinnati (60°/s)	r	0.38	**p< 0.01**
Li et al., (1996)	ACLD (n =	Cincinnati (PT) at 60°/s)	r	0.34	**p< 0.01**
Li et al., (1996)	ACLD (n =	Cincinnati (PT - average power[W]) vs. Cincinnati	r	0.41	**p< 0.01**
Lephart et al.(1992)	ACLD (n =	IAKS (PT at 60°/s)	r	-0.04	ns
Lephart et al.(1992)	ACLD (n =	IAKS (PT at 60°/s)	r	-0.04	ns
	H:Q ratio (assessed between 120 to 179°/s) - No reported correlations.				
	H:Q ratio (assessed between 180 to 239°/s):				
Li et al., (1996)	ACLD (n =	Cincinnati (PT at 180°/s)	r	0.44	**p< 0.01**
Li et al., (1996)	ACLD (n =	Cincinnati (PT at 180°/s)	r	0.37	**p< 0.01**
	H:Q ratio (assessed between 240 to 299°/s):				
Lephart et al.(1992)	ACLD (n =	IAKS (PT at 270°/s)	r	-0.10	ns
	H:Q ratio (Assessed between 300°/s plus) - No reported correlations.				

TABLE 95 - Correlation coefficient values for P-BOMs versus assessments of TW of knee extensors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	<u>TW - Knee extensors:</u>				
Harter et al., (1988)	ACLR (n = 51)	KFR (180°/s)	r	0.14	p = 0.17
Harter et al., (1988)	ACLR (n = 51)	ARS (180°/s)	r	0.31	**p = 0.02**
Harter et al., (1988)	ACLR (n = 51)	10PT (180°/s)	r	0.16	p = 0.15
Harter et al., (1988)	ACLR (n = 51)	POPF (180°/s)	r	0.28	**p = 0.03**
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s (6-months)	r	0.34	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (6-months)	r	0.32	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s(1-year)	r	0.39	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (1-year)	r	0.19	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s (2-year)	r	0.34	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (2-year)	r	0.16	not stated
Kannus (1988)	ACLD (n = 36)	Lysholm (60°/s)	r	0.82	**p< 0.001**
Kannus (1988)	ACLD (n = 36)	Lysholm (60°/s)	rs	0.84	**p< 0.001**
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (1-year)	r	0.59	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (1-year)	r	0.46	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (2-year)	r	0.50	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (2-year)	r	0.19	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (6-months)	r	0.29	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (6-months)	r	0.44	not stated

TABLE 96 - Correlation coefficient values for P-BOMs versus assessments of TW of knee flexors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	<u>TW - Knee flexors:</u>				
Harter et al., (1988)	ACLR (n = 51)	KFR (180°/s)	r	0.12	p= 0.21
Harter et al., (1988)	ACLR (n = 51)	ARS (180°/s)	r	0.18	p= 0.11
Harter et al., (1988)	ACLR (n = 51)	10PT (180°/s)	r	0.12	p= 0.22
Harter et al., (1988)	ACLR (n = 51)	POPF (180°/s)	r	0.33	**p= 0.01**
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s (6-months)	r	0.31	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (6-months)	r	0.11	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s(1-year)	r	0.17	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (1-year)	r	0.06	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 60°/s (2-year)	r	0.28	not stated
Holm et al., (2000)	ACLR (n = 151)	Cincinnati 240°/s (2-year)	r	0.15	not stated
Kannus (1988)	ACLD (n = 36)	Lysholm (60°/s)	r	0.75	**p< 0.001**
Kannus (1988)	ACLD (n = 36)	Lysholm (60°/s)	rs	0.76	**p< 0.001**
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (1-year)	r	0.31	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (1-year)	r	0.18	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (2-year)	r	0.35	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (2-year)	r	0.07	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (60°/s) (6-months)	r	0.43	not stated
Risberg et al., (1999c)	ACLR (n = 60)	Cincinnati (240°/s) (6-months)	r	-0.01	not stated
Harter et al., (1988)	ACLR (n = 51)	KFR (180°/s)	r	0.12	p= 0.21

TABLE 97 - Correlation coefficient values for P-BOMs versus dynamometry assessment of acceleration phase of the knee flexors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	DYNAMOMETRY: ACCELERATION PHASE (KNEE FLEXORS):				
	Acceleration phase assessed (2) between 0 to 59°/s)		**No reported correlations**		
	Acceleration phase assessed (2) between 60 to 119°/s:				
Lephart et al., (1992)	ACLR (n = 41)	IAKS (TAE at 60°/s)	r	0.24	ns
	Acceleration phase assessed (2) between 120 to 179°/s:		**No reported correlations**		
	Acceleration phase assessed (2) between 180 to 239°/s:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (180°/s)	r	0.32	**p= 0.02**
	Acceleration phase assessed (2) between 240 to 299°/s:				
Lephart et al., (1992)	ACLR (n = 41)	IAKS (TAE at 270°/s)	r	0.22	ns
	Acceleration phase assessed (2) 300°/s plus:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300°/s)	r	0.26	p= 0.09
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified)450°/s)	r	0.003	p= 0.99

TABLE 98 - Correlation coefficient values for P-BOMs versus dynamometry assessment of acceleration phase of the knee extensors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	<u>DYNAMOMETRY: ACCELERATION PHASE (KNEE EXTENSORS):</u>				
	<u>Acceleration phase assessed (2) between 0 to 59°/s)</u>		**No reported correlations**		
	<u>Acceleration phase assessed (2) between 60 to 119°/s:</u>				
Lephart et al., (1992)	ACLR (n = 41)	IAKS (TAE at 60°/s)	r	0.26	ns
	<u>Acceleration phase assessed (2) between 120 to 179°/s</u>		**No reported correlations**		
	<u>Acceleration phase assessed (2) between 180 to 239°/s:</u>				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (180°/s)	r	0.67	**p= 0.001**
	<u>Acceleration phase assessed (2) between 240 to 299°/s:</u>				
Lephart et al., (1992)	ACLR (n = 41)	IAKS (TAE at 270°/s)	r	0.23	ns
	<u>Acceleration phase assessed (2) 300°/s plus:</u>				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300°/s)	r	0.59	**p= 0.001**
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (450°/s)	r	0.16	p= 0.31

TABLE 99 - Correlation coefficient values for P-BOMs versus dynamometry assessment of deceleration phase of the knee flexors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	DYNAMOMETRY: DECELERATION PHASE (KNEE FLEXORS):				
	Deceleration phase assessed (2) between 0 to 59°/s)		**No reported correlations**		
	Deceleration phase assessed (2) between 60 to 119°/s		**No reported correlations**		
	Deceleration phase assessed (2) between 120 to 179°/s		**No reported correlations**		
	Deceleration phase assessed (2) between 180 to 239°/s:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (180°/s)	r	0.16	p= 0.24
	Deceleration phase assessed (2) between 240 to 299°/s		**No reported correlations**		
	Deceleration phase assessed (2) 300°/s plus:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300/s)	r	0.08	p= 0.54
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (450°/s)	r	0.03	p= 0.84

TABLE 100 - Correlation coefficient values for P-BOMs versus dynamometry assessment of deceleration phase of the knee extensors.

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient value	Level of significance
	DYNAMOMETRY: DECELERATION PHASE (KNEE EXTENSORS):				
	Deceleration phase assessed (2) between 0 to 59°/s)		**No reported correlations**		
	Deceleration phase assessed (2) between 60 to 119°/s		**No reported correlations**		
	Deceleration phase assessed (2) between 120 to 179°/s		**No reported correlations**		
	Deceleration phase assessed (2) between 180 to 239°/s:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (180°/s)	r	0.27	p= 0.12
	Deceleration phase assessed (2) between 240 to 299°/s		**No reported correlations**		
	Deceleration phase assessed (2) 300°/s plus:				
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (300°/s)	r	0.18	p= 0.15
Wilk et al., (1994)	ACLR (n = 50)	Noyes (modified) (450°/s)	r	0.15	p= 0.22

TABLE 101 - Correlation coefficient values for P-BOMs versus neuromuscular indices of knee performance (EMD and RFD).

	Subjects	P-BOMs	Correlation coefficient	Correlation coefficient Value	Level of significance
	Neuromuscular indices of knee performance (EMD and RFD):				
	EMD:				
Gleeson et al., (2008)	ACLR (n = 9)	Bi-POMs (10 weeks post-surgery)	rs	-0.77	$p < 0.05$
Gleeson et al., (2008)	ACLR (n = 9)	Performance Profile (10-surgery)	rs	-0.84	$p < 0.01$
Gleeson et al., (2008)	ACLR (n = 9)	Performance Profile (8 weeks post-surgery)	rs	-0.81	$p < 0.01$
Gleeson et al., (2008)	ACLR (n = 9)	Performance Profile (pre-surgery)	rs	-0.82	$p < 0.01$
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.74	$p < 0.05$
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.80	$p < 0.01$
	RFD:				
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.74	$p < 0.05$
Yates et al., (2016)	ACLR (n = 9)	Performance Profile	rs	0.80	$p < 0.01$

APPENDIX 8

All correlation coefficient values reported for all Patient-Based Outcome Measures (P-BOMs) and Clinician-Based Outcome Measures (C-BOMs) evaluated amongst the inter-correlations (P-BOMs, C-BOMs, P-BOMs and C-BOM (together), at the acute, intermediate, late phases of rehabilitation.

TABLE 102 - P-BOMs versus P-BOMs at pre-surgery (pooled PPM/CON rehabilitation groups) [n=46]).

P-BOMs	vs.	P-BOMs	Correlation Coefficient.	Significance level.	Hinkle et al., (2003) interpretation.
IKDC	vs.	KOOS (Function)	-0.53	0.001	Moderate (negative)
IKDC	vs.	KOOS (Pain)	-0.59	0.001	Moderate (negative)
IKDC	vs.	KOOS (QoL)	-0.52	0.001	Moderate (negative)
IKDC	vs.	KOOS (Sport/rec)	-0.59	0.05	Moderate (negative)
IKDC	vs.	KOOS (Symptoms)	-0.58	0.001	Moderate (negative)
IKDC	vs.	Lysholm	0.65	0.001	Moderate (positive)
KOOS (Function)	vs.	KOOS (QoL)	0.44	0.001	Low (positive)
KOOS (Function)	vs.	KOOS (Sport/rec)	0.58	0.001	Moderate (positive)
KOOS (Pain)	vs.	KOOS (Function)	0.91	0.001	Very high (positive)
KOOS (Pain)	vs.	KOOS (QoL)	0.42	0.01	Low (positive)
KOOS (Pain)	vs.	KOOS (Sport/rec)	0.55	0.001	Moderate (positive)
KOOS (Sport/rec)	vs.	KOOS (QoL)	0.62	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (Function)	0.61	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (Pain)	0.66	0.001	Moderate (positive)
KOOS (Symptoms)	vs.	KOOS (QoL)	0.37	0.01	Low (positive)
KOOS (Symptoms)	vs.	KOOS (Sport/rec)	0.37	0.01	Low (positive)
Lysholm	vs.	KOOS (Function)	-0.57	0.001	Moderate (negative)
Lysholm	vs.	KOOS (Pain)	-0.60	0.001	Moderate (negative)
Lysholm	vs.	KOOS (QoL)	-0.45	0.001	Low (negative)
Lysholm	vs.	KOOS (Symptoms)	-0.45	0.001	Low (negative)
VAS (Pain)	vs.	IKDC	-0.41	0.01	Low (negative)
VAS (Pain)	vs.	KOOS (Function)	0.29	0.05	No or negligible
VAS (Pain)	vs.	KOOS (Pain)	.042	0.01	Low (positive)
VAS (Pain)	vs.	KOOS (Symptoms)	0.36	0.01	Low (positive)

TABLE 103 - C-BOMs versus C-BOMs at pre-surgery [pooled PPM/CON rehabilitation groups] [n=46].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	Single-leg-hop (distance)	**vs.**	PF	0.43	0.001	Low (positive)
	SMP-FE	**vs.**	RFD	0.39	0.01	Low (positive)
Extensors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.57	0.001	Moderate (positive)
	PF	**vs.**	Single-leg-hop (distance)	0.33	0.05	Low (positive)
Flexors (non-injured):	SMP-FE	**vs.**	PF	-0.33	0.05	Low (negative)
Extensors (non-injured):	PF	**vs.**	Single-leg-hop (distance)	0.33	0.05	Low (positive)
	SMP-FE	**vs.**	Single-leg-hop (distance)	0.36	0.01	Low (positive)
	SMP-FE	**vs.**	RFD	0.47	0.001	Low (positive)

TABLE 104 - P-BOMs versus C-BOMs at pre-surgery [pooled PPM/CON rehabilitation groups] [n=46].

KNEE MUSCLES [FLEXORS/EXTENSORS], AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	KOOS (Pain)	**vs.**	Single-leg-hop (distance)	-0.29	0.05	No or negligible
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.37	0.05	Low (negative)
Extensors (injured):	KOOS (Pain)	**vs.**	Single-leg-hop (distance)	-0.29	0.05	No or negligible
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.37	0.05	Low (negative)
	KOOS (Pain)	**vs.**	PF	-0.42	0.01	Low (negative)
	KOOS (Function)	**vs.**	PF	-0.42	0.01	Low (negative)
	KOOS (QoL)	**vs.**	RFD	-0.42	0.01	Low (negative)
Flexors (non-injured):	IKDC	**vs.**	SMP-FE	-0.31	0.05	Low (negative)
Extensors (non-injured):	**NR**	vs.	**NR**			

TABLE 105 - P-BOMs versus P-BOMs at acute phase (0-6 weeks) [PPM rehabilitation group condition] [n = 23].

P-BOMs.	vs.	**P-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
IKDC	**vs.**	VAS (Pain)	-0.71	0.001	High (negative)
VAS (Pain)	**vs.**	KOOS (Function)	-0.61	0.001	Moderate (negative)
IKDC	**vs.**	KOOS (Function)	-0.60	0.001	Moderate (negative)
Lysholm	**vs.**	VAS (Pain)	-0.55	0.01	Moderate (negative)
IKDC	**vs.**	KOOS (QoL)	-0.45	0.05	Low (negative)
KOOS (Sport/rec)	**vs.**	KOOS (Function)	0.45	0.05	Low (positive)
KOOS (Pain)	**vs.**	KOOS (Symptoms)	0.48	0.05	Low (positive)
KOOS (QoL)	**vs.**	KOOS (Pain)	0.49	0.01	Low (positive)
KOOS (QoL)	**vs.**	KOOS (Function)	0.49	0.01	Low (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Pain)	0.50	0.01	Moderate (positive)
VAS (Pain)	**vs.**	KOOS (Pain)	0.63	0.001	Moderate (positive)
IKDC	**vs.**	KOOS (Pain)	0.66	0.001	Moderate (positive)
Lysholm	**vs.**	IKDC	0.77	0.001	High (positive)
KOOS (QoL)	**vs.**	KOOS (Sport/rec)	0.77	0.001	High (positive)
KOOS (Function)	**vs.**	KOOS (Pain)	0.86	0.001	High (positive)

TABLE 106 - P-BOMs versus P-BOMs at intermediate phase (6-12 weeks) [PPM rehabilitation group condition] [n = 23].

P-BOMs.	vs.	P-BOMs.	Correlation Coefficient.	Significance level.	Hinkle et al., (2003) interpretation.
Lysholm	**vs.**	KOOS (Function)	-0.83	0.001	High (negative)
IKDC	**vs.**	KOOS (QoL)	-0.80	0.001	High (negative)
IKDC	**vs.**	KOOS (Function)	-0.67	0.001	Moderate (negative)
Lysholm	**vs.**	KOOS (Pain)	-0.61	0.001	Moderate (negative)
IKDC	**vs.**	KOOS (Pain)	-0.60	0.001	Moderate (negative)
IKDC	**vs.**	KOOS (Sport/rec)	-0.56	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (Symptoms)	-0.52	0.01	Moderate (negative)
Lysholm	**vs.**	VAS (Pain)	-0.49	0.01	Low (negative)
Lysholm	**vs.**	KOOS (QoL)	-0.42	0.05	Low (negative)
KOOS (Function)	**vs.**	KOOS (Pain)	0.60	0.001	Moderate (positive)
Lysholm	**vs.**	IKDC	0.65	0.001	Moderate (positive)
KOOS (Function)	**vs.**	KOOS (Symptoms)	0.75	0.001	High (positive)

TABLE 107 - P-BOMs versus P-BOMs at late phase (12-24 weeks) [PPM rehabilitation group condition] [n = 23].

P-BOMs.	**vs.**	**P-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
IKDC	**vs.**	KOOS (QoL)	-0.91	0.001	Very high (negative)
Lysholm	**vs.**	KOOS (Pain)	-0.90	0.001	Very high (negative)
Lysholm	**vs.**	KOOS (Function)	-0.88	0.001	High (negative)
Lysholm	**vs.**	KOOS (Sport/rec)	-0.88	0.001	High (negative)
IKDC	**vs.**	KOOS (Pain)	-0.83	0.001	High (negative)
IKDC	**vs.**	VAS (Pain)	-0.81	0.001	High (negative)
IKDC	**vs.**	KOOS (Sport/rec)	-0.80	0.001	High (negative)
Lysholm	**vs.**	KOOS (QoL)	-0.68	0.001	Moderate (negative)
Lysholm	**vs.**	KOOS (Symptoms)	-0.66	0.001	Moderate (negative)
IKDC	**vs.**	KOOS (Function)	-0.65	0.001	Moderate (negative)
Lysholm	**vs.**	VAS (Pain)	-0.59	0.001	Moderate (negative)
Performance Profile (non-injured)	**vs.**	KOOS (Symptoms)	-0.59	0.01	Moderate (negative)
Performance Profile (non-injured)	**vs.**	KOOS (Function)	-0.52	0.05	Moderate (negative)
VAS (Pain)	**vs.**	KOOS (Pain)	0.42	0.05	Low (positive)
VAS (Pain)	**vs.**	KOOS (Sport/rec)	0.48	0.05	Low (positive)
KOOS (Pain)	**vs.**	KOOS (Symptoms)	0.51	0.01	Moderate (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Symptoms)	0.57	0.001	Moderate (positive)
KOOS (QoL)	**vs.**	KOOS (Pain)	0.58	0.001	Moderate (positive)
Performance Profile (non-injured)	**vs.**	Lysholm	0.61	0.01	Moderate (positive)
KOOS (QoL)	**vs.**	KOOS (Sport/rec)	0.62	0.001	Moderate (positive)
Performance Profile (non-injured)	**vs.**	Performance Profile (injured)	0.62	0.01	Moderate (positive)
KOOS (Function)	**vs.**	KOOS (Symptoms)	0.71	0.001	High (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Function)	0.80	0.001	High (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Pain)	0.83	0.001	High (positive)
Lysholm	**vs.**	IKDC	0.86	0.001	High (positive)
KOOS (Function)	**vs.**	KOOS (Pain)	0.88	0.001	High (positive)
VAS (Pain)	**vs.**	KOOS (QoL)	0.96	0.001	Very high (positive)

TABLE 108 - P-BOMs versus P-BOMs at acute phase (0-6 weeks) [control group condition] [n = 23].

P-BOMs.	**vs.**	**P-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
KOOS (Function)	**vs.**	IKDC	-0.56	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (Function)	-0.55	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (Sport/rec)	-0.51	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (QoL)	-0.50	0.01	Moderate (negative)
IKDC	**vs.**	VAS (Pain)	-0.47	0.05	Low (negative)
KOOS (QoL)	**vs.**	IKDC	-0.44	0.05	Low (negative)
KOOS (Sport/rec)	**vs.**	IKDC	-0.44	0.05	Low (negative)
KOOS (QoL)	**vs.**	KOOS (Function)	0.44	0.05	Low (positive)
KOOS (QoL)	**vs.**	KOOS (Sport/rec)	0.59	0.001	Moderate (positive)
Lysholm	**vs.**	IKDC	0.67	0.001	Moderate (positive)

TABLE 109 - P-BOMs versus P-BOMs at intermediate phase (6-12 weeks) [control group condition] [n = 23].

P-BOMs.	**vs.**	**P-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Performance Profile (non-injured)	**vs.**	VAS (Pain)	-0.59	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (Function)	-0.54	0.01	Moderate (negative)
Lysholm	**vs.**	KOOS (Pain)	-0.48	0.05	Low (negative)
KOOS (Pain)	**vs.**	IKDC	-0.45	0.05	Low (negative)
Lysholm	**vs.**	KOOS (QoL)	-0.41	0.05	Low (negative)
Lysholm	**vs.**	IKDC	0.60	0.001	Moderate (positive)
KOOS (Function)	**vs.**	KOOS (Pain)	0.68	0.001	Moderate (positive)

TABLE 110 - P-BOMs versus P-BOMs at late phase (12-24 weeks) [control group condition] [n = 23].

P-BOMs.	**vs.**	**P-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
KOOS (Pain)	**vs.**	IKDC	-0.92	0.001	Very high (negative)
Lysholm	**vs.**	KOOS (Function)	-0.85	0.001	High (negative)
Lysholm	**vs.**	KOOS (Pain)	-0.84	0.001	High (negative)
KOOS (Sport/rec)	**vs.**	IKDC	-0.80	0.001	High (negative)
KOOS (Function)	**vs.**	IKDC	-0.80	0.001	High (negative)
KOOS (QoL)	**vs.**	IKDC	-0.71	0.001	High (negative)
Lysholm	**vs.**	KOOS (QoL)	-0.71	0.001	High (negative)
Lysholm	**vs.**	VAS (Pain)	-0.53	0.01	Moderate (negative)
IKDC	**vs.**	VAS (Pain)	-0.53	0.01	Moderate (negative)
KOOS (Function)	**vs.**	VAS (Pain)	0.46	0.05	Low (positive)
KOOS (Sport/rec)	**vs.**	VAS (Pain)	0.51	0.01	Moderate (positive)
KOOS (Pain)	**vs.**	VAS (Pain)	0.54	0.01	Moderate (positive)
Performance Profile (non-injured)	**vs.**	Performance Profile (injured)	0.55	0.05	Moderate (positive)
KOOS (QoL)	**vs.**	KOOS (Function)	0.59	0.001	Moderate (positive)
KOOS (QoL)	**vs.**	VAS (Pain)	0.62	0.001	Moderate (positive)
KOOS (QoL)	**vs.**	KOOS (Pain)	0.74	0.001	High (positive)
Lysholm	**vs.**	IKDC	0.78	0.001	High (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Function)	0.84	0.001	High (positive)
KOOS (Function)	**vs.**	KOOS (Pain)	0.88	0.001	High (positive)
KOOS (Sport/rec)	**vs.**	KOOS (Pain)	0.90	0.001	Very high (positive)

TABLE 111 - C-BOMs versus C-BOMs at acute phase (0-6 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	EMD	**vs.**	PF	0.52	0.05	Moderate (positive)
Extensors (injured):	EMD	**vs.**	ATFD	0.58	0.01	Moderate (positive)
	SMP-FE	**vs.**	RFD	0.41	0.05	Low (positive)
Flexors (non-injured):	RFD	**vs.**	PF	0.46	0.05	Low (positive)
	EMD	**vs.**	PF	-0.49	0.01	Low (negative)
	SMP-FE	**vs.**	RFD	0.50	0.01	Moderate (positive)
Extensors (non-injured):	RFD	**vs.**	ATFD	-0.52	0.01	Moderate (negative)
	SMP-FE	**vs.**	ATFD	-0.46	0.05	Low (negative)
	SMP-FE	**vs.**	RFD	0.52	0.01	Moderate (positive)

TABLE 112 - C-BOMs versus C-BOMs at intermediate phase (6-12 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.42	0.05	Low (positive)
	SMP-FE	**vs.**	Single-leg-hop (distance)	-0.60	0.001	Moderate (negative)
Extensors (injured):	**NR**	**vs.**	**NR**			
Flexors (non-injured):	**NR**	**vs.**	**NR**			
Extensors (non-injured):	SMP-FE	**vs.**	EMD	-0.61	0.001	Moderate (negative)

TABLE 113 - C-BOMs versus C-BOMs at late phase (12-24 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.53	0.01	Moderate (positive)
	EMD	**vs.**	PF	0.83	0.001	High (positive)
Extensors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.48	0.05	Low (positive)
	EMD	**vs.**	PF	0.64	0.001	Moderate (positive)
	SMP-FE	**vs.**	RFD	0.52	0.01	Moderate (positive)
Flexors (non-injured):	PF	**vs.**	Single-leg-hop (distance)	0.43	0.05	Low (positive)
	RFD	**vs.**	ATFD	-0.48	0.01	Low (negative)
	EMD	**vs.**	PF	0.58	0.001	Moderate (positive)
Extensors (non-injured):	PF	**vs.**	Single-leg-hop (distance)	0.43	0.05	Low (positive)
	EMD	**vs.**	PF	0.71	0.001	High (positive)
	SMP-FE	**vs.**	RFD	0.62	0.001	Moderate (positive)

TABLE 114 - C-BOMs versus C-BOMs at acute phase (0-6 weeks) [control group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	SMP-FE	**vs.**	PF	-0.47	0.05	Low (negative)
Extensors (injured):	SMP-FE	**vs.**	PF	-0.48	0.05	Low (negative)
Flexors (non-injured):	**NR**	**vs.**	**NR**			
Extensors (non-injured):	**NR**	**vs.**	**NR**			

TABLE 115 - C-BOMs versus C-BOMs at intermediate phase (6-12 weeks) [CON rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	SMP-FE	**vs.**	PF	-0.61	0.001	Moderate (negative)
Extensors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.58	0.01	Moderate (positive)
	SMP-FE	**vs.**	PF	-0.51	0.01	Moderate (negative)
	SMP-FE	**vs.**	RFD	0.50	0.01	Moderate (positive)
Flexors (non-injured):	SMP-FE	**vs.**	PF	-0.68	0.001	Moderate (negative)
	SMP-FE	**vs.**	RFD	0.56	0.01	Moderate (positive)
Extensors (non-injured):	SMP-FE	**vs.**	PF	-0.57	0.01	Moderate (negative)
	SMP-FE	**vs.**	RFD	0.54	0.01	Moderate (positive)

TABLE 116 - C-BOMs versus C-BOMs at late phase (12-24 weeks) [CON rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**C-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	SMP-FE	**vs.**	RFD	0.48	0.05	Low (positive)
Extensors (injured):	PF	**vs.**	Single-leg-hop (distance)	0.65	0.001	Moderate (positive)
	SMP-FE	**vs.**	RFD	0.50	0.01	Moderate (positive)
Flexors (non-injured):	PF	**vs.**	Single-leg-hop (distance)	0.41	0.05	Low (positive)
	SMP-FE	**vs.**	PF	-0.47	0.05	Low (negative)
Extensors (non-injured):	ATFD	**vs.**	Single-leg-hop (distance)	0.49	0.01	Low (positive)
	PF	**vs.**	Single-leg-hop (distance)	0.48	0.05	Low (positive)

TABLE 117 - P-BOMs versus C-BOMs at acute phase (0-6 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	KOOS (Function)	**vs.**	ATFD	0.46	0.05	Low (positive)
	KOOS (Symptoms)	**vs.**	PF	-0.50	0.01	Moderate (negative)
	KOOS (Pain)	**vs.**	PF	-0.64	0.001	Moderate (negative)
	KOOS (Function)	**vs.**	PF	-0.44	0.05	Low (negative)
	KOOS (Sport/rec)	**vs.**	SMP-FE	0.44	0.05	Low (positive)
Extensors (injured):	KOOS (Function)	**vs.**	ATFD	0.46	0.05	Low (positive)
	VAS (Pain)	**vs.**	PF	-0.45	0.05	Low (negative)
	KOOS (Function)	**vs.**	RFD	0.43	0.05	Low (positive)
	KOOS (QoL)	**vs.**	RFD	0.42	0.05	Low (positive)
	VAS (Pain)	**vs.**	EMD	0.42	0.05	Low (positive)
	Performance Profile (injured)	**vs.**	SMP-FE	0.42	0.05	Low (positive)
Flexors (non-injured):	KOOS (Symptoms)	**vs.**	PF	-0.42	0.05	Low (negative)
	KOOS (QoL)	**vs.**	RFD	0.46	0.05	Low (positive)
	Performance Profile (non-injured)	**vs.**	RFD	0.46	0.05	Low (positive)
Extensors (non-injured):	KOOS (Symptoms)	**vs.**	PF	-0.42	0.05	Low (negative)
	IKDC	**vs.**	RFD	-0.50	0.01	Moderate (negative)

TABLE 118 - P-BOMs versus C-BOMs at intermediate phase (6-12 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS], AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**		**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	Lysholm	**vs.**	Single-leg-hop (distance)	-0.51	0.01	Moderate (negative)
	KOOS (Symptoms)	**vs.**	Single-leg-hop (distance)	-0.51	0.01	Moderate (negative)
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.48	0.01	Low (negative)
	VAS (Pain)	**vs.**	PF	-0.43	0.05	Low (negative)
	Lysholm	**vs.**	PF	0.46	0.05	Low (positive)
	KOOS (Symptoms)	**vs.**	PF	-0.50	0.01	Moderate (negative)
	Performance Profile (injured)	**vs.**	PF	0.55	0.01	Moderate (positive)
	KOOS (Symptoms)	**vs.**	RFD	0.43	0.05	Low (positive)
	KOOS (Pain)	**vs.**	RFD	0.51	0.01	Moderate (positive)
	KOOS (Function)	**vs.**	RFD	0.46	0.05	Low (positive)
	VAS (Pain)	**vs.**	SMP-FE	0.42	0.05	Low (positive)
	Lysholm	**vs.**	SMP-FE	-0.46	0.05	Low (negative)
	KOOS (Function)	**vs.**	SMP-FE	0.53	0.01	Moderate (positive)
Extensors (injured):	Lysholm	**vs.**	Single-leg-hop (distance)	0.51	0.01	Moderate (positive)
	KOOS (Symptoms)	**vs.**	Single-leg-hop (distance)	-0.05	0.01	Moderate (negative)
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.48	0.01	Low (negative)
	VAS (Pain)	**vs.**	PF	-0.47	0.05	Low (negative)
	KOOS (QoL)	**vs.**	PF	0.54	0.01	Moderate (positive)
	IKDC	**vs.**	RFD	-0.55	0.01	Moderate (negative)
	KOOS (Sport/rec)	**vs.**	RFD	0.47	0.05	Low (positive)
	KOOS (Sport/rec)	**vs.**	EMD	-0.43	0.05	Low (negative)
	VAS (Pain)	**vs.**	SMP-FE	0.60	0.001	Moderate (positive)
	IKDC	**vs.**	SMP-FE	-0.53	0.01	Moderate (negative)

	Lysholm	**vs.**	SMP-FE	-0.58	0.001	Moderate (negative)
	KOOS (Symptoms)	**vs.**	SMP-FE	0.57	0.01	Moderate (positive)
	KOOS (Function)	**vs.**	SMP-FE	0.64	0.001	Moderate (positive)
Flexors (non-injured):	VAS (Pain)	**vs.**	Single-leg-hop (distance)	-0.42	0.05	Low (negative)
	Lysholm	**vs.**	Single-leg-hop (distance)	0.46	0.05	Low (positive)
	KOOS (Symptoms)	**vs.**	Single-leg-hop (distance)	-0.54	0.01	Moderate (negative)
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.49	0.01	Low (negative)
	IKDC	**vs.**	ATFD	0.46	0.05	Low (positive)
	KOOS (QoL)	**vs.**	ATFD	-0.52	0.01	Moderate (negative)
	VAS (Pain)	**vs.**	PF	-0.52	0.01	Moderate (negative)
	KOOS (Symptoms)	**vs.**	PF	-0.68	0.001	Moderate (negative)
	KOOS (Function)	**vs.**	PF	-0.49	0.01	Low (negative)
	KOOS (Sport/rec)	**vs.**	EMD	-0.43	0.05	Low (negative)
Extensors (non-injured):	VAS (Pain)	**vs.**	Single-leg-hop (distance)	-0.42	0.05	Low (negative)
	Lysholm	**vs.**	Single-leg-hop (distance)	0.46	0.05	Low (positive)
	KOOS (Symptoms)	**vs.**	Single-leg-hop (distance)	-0.54	0.01	Moderate (negative)
	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.49	0.01	Low (negative)
	IKDC	**vs.**	ATFD	0.46	0.05	Low (positive)
	KOOS (QoL)	**vs.**	ATFD	-0.52	0.01	Moderate (negative)
	VAS (Pain)	**vs.**	PF	-0.52	0.01	Moderate (negative)
	KOOS (Symptoms)	**vs.**	PF	-0.68	0.001	Moderate (negative)
	KOOS (Function)	**vs.**	PF	-0.49	0.01	Low (negative)
	IKDC	**vs.**	RFD	-0.47	0.05	Low (negative)
	IKDC	**vs.**	EMD	0.48	0.05	Low (positive)
	IKDC	**vs.**	SMP-FE	-0.70	0.001	High (negative)
	KOOS (Sport/rec)	**vs.**	SMP-FE	0.43	0.05	Low (positive)
	KOOS (QoL)	**vs.**	SMP-FE	0.62	0.001	Moderate (positive)

TABLE 119 - P-BOMs versus C-BOMs at late phase (12-24 weeks) [PPM rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**		**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.43	0.05	Low (negative)
	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)
	IKDC	**vs.**	PF	-0.42	0.05	Low (negative)
	KOOS (QoL)	**vs.**	PF	0.65	0.001	Moderate (positive)
	VAS (Pain)	**vs.**	EMD	0.91	0.001	Very high (positive)
	IKDC	**vs.**	EMD	-0.69	0.001	Moderate (negative)
	Lysholm	**vs.**	EMD	-0.48	0.05	Low (negative)
	KOOS (QoL)	**vs.**	EMD	0.87	0.001	High (positive)
	Lysholm	**vs.**	SMP-FE	-0.43	0.05	Low (negative)
	KOOS (Pain)	**vs.**	SMP-FE	0.42	0.05	Low (positive)
	KOOS (Function)	**vs.**	SMP-FE	0.56	0.01	Moderate (positive)
	KOOS (Sport/rec)	**vs.**	SMP-FE	0.48	0.05	Low (positive)
Extensors (injured):	KOOS (Function)	**vs.**	Single-leg-hop (distance)	-0.43	0.05	Low (negative)
	VAS (Pain)	**vs.**	PF	0.62	0.001	Moderate (positive)
	IKDC	**vs.**	PF	-0.48	0.05	Low (negative)
	KOOS (QoL)	**vs.**	PF	0.65	0.001	Moderate (positive)
	VAS (Pain)	**vs.**	EMD	0.91	0.001	Very high (positive)
	IKDC	**vs.**	EMD	-0.73	0.001	High (negative)
	Lysholm	**vs.**	EMD	-0.47	0.05	Low (negative)
	KOOS (QoL)	**vs.**	EMD	0.93	.001	Very high (positive)

Flexors (non-injured):	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)
	IKDC	**vs.**	PF	-0.46	0.05	Low (negative)
	KOOS (QoL)	**vs.**	PF	0.71	0.001	High (positive)
	KOOS (Pain)	**vs.**	RFD	-0.44	0.05	Low (negative)
	KOOS (Sport/rec)	**vs.**	RFD	-0.42	0.05	Low (negative)
	VAS (Pain)	**vs.**	EMD	0.95	0.001	Very high (positive)
	IKDC	**vs.**	EMD	-0.76	0.001	High (negative)
	Lysholm	**vs.**	EMD	-0.53	0.01	Moderate (negative)
	KOOS (QoL)	**vs.**	EMD	0.90	0.001	Very high (positive)
	KOOS (Symptoms)	**vs.**	SMP-FE	-0.61	0.001	Moderate (negative)
Extensors (non-injured):	VAS (Pain)	**vs.**	PF	0.71	0.001	High (positive)
	IKDC	**vs.**	PF	-0.46	0.05	Low (negative)
	KOOS (QoL)	**vs.**	PF	0.71	0.001	High (positive)
	VAS (Pain)	**vs.**	EMD	0.90	0.001	Very high (positive)
	IKDC	**vs.**	EMD	-0.72	0.001	High (negative)
	Lysholm	**vs.**	EMD	-0.50	0.01	Moderate (negative)
	KOOS (QoL)	**vs.**	EMD	0.91	0.001	Very high (positive)

TABLE 120 - P-BOMs versus C-BOMs at acute phase (0-6 weeks) [CON rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	IKDC	**vs.**	SMP-FE	-0.42	0.05	Low (negative)
Extensors (injured):	IKDC	**vs.**	SMP-FE	-0.45	0.05	Low (negative)
	Performance Profile (injured)	**vs.**	SMP-FE	0.45	0.05	Low (positive)
Flexors (non-injured):	VAS (Pain)	**vs.**	RFD	0.62	0.001	Moderate (positive)
Extensors (non-injured):	KOOS (Symptoms)	**vs.**	EMD	0.68	0.001	Moderate (positive)

TABLE 121 - P-BOMs versus C-BOMs at intermediate phase (6-12 weeks) [CON rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	KOOS (QoL)	**vs.**	Single-leg-hop (distance)	-0.48	0.05	Low (negative)
	Lysholm	**vs.**	ATFD	0.60	0.001	Moderate (positive)
	KOOS (Pain)	**vs.**	ATFD	-0.60	0.001	Moderate (negative)
	KOOS (Function)	**vs.**	ATFD	-0.62	0.001	Moderate (negative)
	KOOS (QoL)	**vs.**	PF	-0.51	0.01	Moderate (negative)
Extensors (injured):	KOOS (QoL)	**vs.**	Single-leg-hop (distance)	-0.48	0.05	Low (negative)
	Lysholm	**vs.**	ATFD	0.60	0.001	Moderate (positive)
	KOOS (Pain)	**vs.**	ATFD	-0.60	0.001	Moderate (negative)
	KOOS (Function)	**vs.**	ATFD	-0.62	0.001	Moderate (negative)
	KOOS (QoL)	**vs.**	PF	-0.62	0.001	Moderate (negative)
	KOOS (Sport/rec)	**vs.**	SMP-FE	-0.48	0.05	Low (negative)
Flexors (non-injured):	Lysholm	**vs.**	Single-leg-hop (distance)	0.46	0.05	Low (positive)
	KOOS (Sport/rec)	**vs.**	Single-leg-hop (distance)	-0.43	0.05	Low (negative)
	KOOS (QoL)	**vs.**	Single-leg-hop (distance)	-0.49	0.01	Low (negative)
	IKDC	**vs.**	RFD	0.43	0.05	Low (positive)
	KOOS (QoL)	**vs.**	EMD	0.50	0.01	Moderate (positive)
Extensors (non-injured):	Lysholm	**vs.**	Single-leg-hop (distance)	0.46	0.05	Low (positive)
	KOOS (Sport/rec)	**vs.**	Single-leg-hop (distance)	-0.43	0.05	Low (negative)
	KOOS (QoL)	**vs.**	Single-leg-hop (distance)	-0.49	0.01	Low (negative)
	KOOS (Sport/rec)	**vs.**	RFD	-0.46	0.05	Low (negative)
	Lysholm	**vs.**	SMP-FE	0.43	0.05	Low (positive)

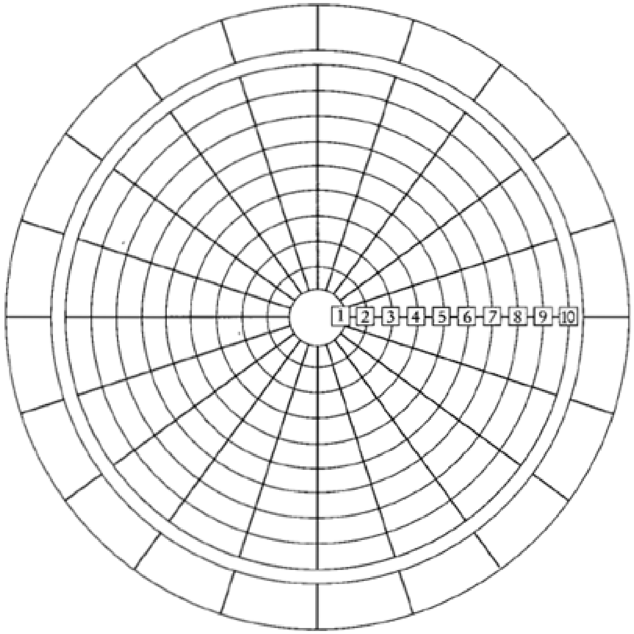
TABLE 122 - P-BOMs versus C-BOMs at late phase (12-24 weeks) [CON rehabilitation group condition] [n = 23].

KNEE MUSCLES [FLEXORS/EXTENSORS]**,** AND **LIMBS** [NON-INJURED/ LIMB] EVALUATED.	**P-BOMs.**	**vs.**	**C-BOMs.**	**Correlation Coefficient.**	**Significance level.**	**Hinkle et al., (2003) interpretation.**
Flexors (injured):	**NR**	vs.	**NR**			
Extensors (injured):	KOOS (Symptoms)	**vs.**	PF	0.57	0.001	Moderate (positive)
Flexors (non-injured):	IKDC	**vs.**	ATFD	0.50	0.01	Moderate (positive)
	KOOS (Pain)	**vs.**	ATFD	-0.48	0.05	Low (negative)
	KOOS (Sport/rec)	**vs.**	ATFD	-0.45	0.05	Low (negative)
	KOOS (QoL)	**vs.**	ATFD	-0.44	0.05	Low (negative)
	KOOS (Symptoms)	**vs.**	PF	0.52	0.01	Moderate (positive)
Extensors (non-injured):	IKDC	**vs.**	ATFD	0.50	0.01	Moderate (positive)
	KOOS (Pain)	**vs.**	ATFD	-0.48	0.05	Low (negative)
	KOOS (Sport/rec)	**vs.**	ATFD	-0.45	0.05	Low (negative)
	KOOS (QoL)	**vs.**	ATFD	-0.44	0.05	Low (negative)

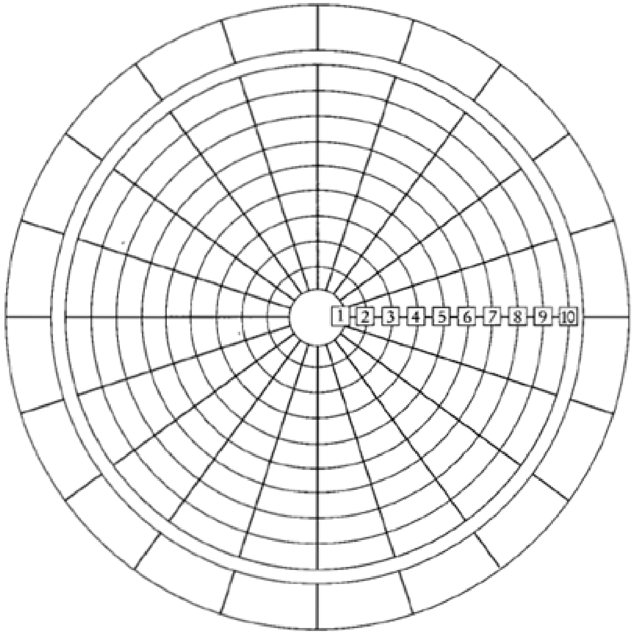
APPENDIX 9

Performance Profile (empty).

“What, in your opinion are the ‘elements’ of your knee in ‘need’ of physical rehabilitation or the ‘elements’ to be improvement upon to obtain full recovery?”



INJURED LIMB



NON-INJURED LIMB

1. **“How are you feeling at the present time on each of the ‘elements’ you have listed?”**
(Response Scale, [0] ‘my knee feels far from recovered’ to [10] ‘my knee feels fully recovered’)

2. **“How important are each of the ‘elements’ you have listed? Please use the scale below, to rank in order of importance, the ‘elements’ which you feel need to be improved upon first to obtain full recovery?”**

APPENDIX 10

Participant Information Sheet

Queen Margaret University
EDINBURGH
School of Health Sciences
Queen Margaret University Drive
Musselburgh
East Lothian
EH21 6UU

The Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS Trust
National Centre for Sport Injury Surgery
Gobowen
Oswestry
Shropshire
SY10 7AG

PROJECT TITLE:
Effects of reconstruction surgery and individualised rehabilitation on neuromuscular, sensorimotor and musculoskeletal performance in patients with anterior cruciate ligament

PARTICIPANT INFORMATION SHEET

You are being invited to take part in the above titled research study. Before you decide to participate, it is important for you to understand why this research is being carried out and what it will involve. Please take your time to read the following information sheet and please feel free to ask any questions if there is anything that is not explained clearly. If you would like more information, please contact the research team (contact details are provided at the end of this information sheet).

WHAT IS THE PURPOSE OF THE STUDY?

This study is part of a doctoral research programme that is currently being undertaken at Queen Margaret University, Edinburgh. The research team are investigating whether we can enhance the rehabilitation that you will be receiving following your anterior cruciate ligament reconstruction surgery.

This rehabilitative programme is detailed in the anterior cruciate ligament surgery and rehabilitation patient advice booklet you have already received. If you have not yet received this, please contact the physiotherapy team. This information guide provides you with examples of the physiotherapy programme you are to receive. This will include strength, endurance and other related techniques used within the field of physiotherapy. It is important that you follow the instructions given to you by the physiotherapy team as they will be important for your recovery following your surgery.

The purpose of this study is to test the effectiveness of rehabilitation involving an especially 'individualised' approach to rehabilitation and compare this technique to the normal rehabilitation programme that is currently being used at Robert Jones & Agnes Hunt Orthopaedic Hospital, Oswestry.

WHY HAVE I BEEN CHOSEN?

In this study, the research team will be investigating patients (like yourself) who have elected to undergo anterior cruciate ligament reconstruction knee surgery and who are otherwise medically fit. The reason you are being invited to take part in this study is that you fit this description.

We are hoping to recruit 75 participants for this trial that involves random-allocation of patients to the types of rehabilitation which are being compared (randomised control trial).

DO I HAVE TO TAKE PART?

Participation in this study is entirely voluntary and you are free to decline participation or to withdraw from the study at any time. You do not need to give any reasons if you decide to leave the study. If you do decide to withdraw, you will continue your rehabilitation as normal with no prejudice.

WHAT WILL HAPPEN TO ME IF I TAKE PART AND WHAT WOULD I HAVE TO DO?
The research team would like to find out, whether or not the current way of rehabilitating patients who have had your type of surgery can be improved upon. To find this out, the research team need to make comparisons between the different styles of rehabilitation. To do this, the research team will put participants into groups that will each experience a different style of rehabilitation. The results will be compared to see which one, if any, is most beneficial. You will be randomly selected (by chance) into one of three groups. It is important to note that no matter which group you are allocated into, you will receive the same standard of care and rehabilitation that is routinely implemented as part as your physiotherapeutic treatment.

Throughout your rehabilitation programme you will be attending the physiotherapy clinic approximately 15-20 times over the 24-week rehabilitative period. It is important that you attend all scheduled appointments with your physiotherapist. However, if you cannot attend for whatever reason, the research team or physiotherapists might contact you by email, letter or telephone to discuss your rehabilitation progress.

Depending upon which group you have been randomly allocated into, you might be asked to complete a questionnaire during your scheduled physiotherapy appointment. This will take no longer than 3 minutes to complete typically. However, during your first session, its completion might take longer (up to 15 minutes) because the research team will introduce and explain about any questionnaire needing completion.

During your rehabilitation programme, you will need to attend up to four assessment sessions. The research team with gain the majority of the information required for the study from these assessment sessions, and so it will be very important that you attend. These assessments sessions will last approximately one hour and will take place on a day that you would normally attend the physiotherapy clinic. Your first appointment for assessment will be prior to your surgery.

Depending on the group to which you are allocated, you will be assessed typically when you visit hospital for your routine outpatient check-ups at 6 weeks following your surgery, at 12 weeks following surgery, and lastly when your rehabilitation programme is completed at 24 weeks.

Within these assessment sessions, you will be tested using advanced computerised data acquisition equipment and software. The research team hope you will find these assessment sessions informative and interesting, providing you with additional time to ask questions and to learn more about your rehabilitation.

We will be monitoring aspects of knee joint performance such as:

The strength of your leg muscles and your ability to repeat brief strength tasks accurately. This allows us to check how well the muscles can produce force to protect the joint efficiently.

How quickly your leg muscles can react to a brief and painless magnetic pulse. This allows us to safely check how quickly the muscles could produce force to protect the joint in an emergency, such as if you were to trip or land awkwardly from a jump.
The laxity/looseness of your knee will also be tested. This allows us to check how well the rehabilitation is affecting the stability of the knee joint.
How the above factors change following a brief fatigue task. This allows us to check the extent to which muscle fatigue could lessen your ability to protect the knee joint during exercise and helps us to gauge a safe return to sport or work-related activities.

You will also be asked to complete questionnaires about your knee, and keep a weekly diary of your rehabilitation. It is anticipated that entering information into the diary should take no longer than 10 minutes per week to complete, and recorded over the 24-week period.

WHAT ARE THE POSSIBLE DISADVANTAGES AND RISKS, AND WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

No matter which rehabilitation group you are allocated into, there will be no extra clinical risks or disadvantages to yourself. This is because all participants in this study will be performing the same exercises at the same stage during the rehabilitation programme. In addition, taking part might be more beneficial to your recovery, and the information the research team gathers from this study might inform and improve future clinical practice.

WHAT HAPPENS WHEN THE RESEARCH STUDY STOPS?

The research findings may inform the research team that one way of rehabilitating patients is better than another. This will then alter the way the physiotherapy team suggest patients rehabilitate in the future.

If you wish, after the research is complete, we can disseminate the findings from the study to you.

The findings may also be written and published in medical/scientific journals to aid other clinicians and patients elsewhere. Neither you nor your data will be identifiable in these publications.

WILL MY TAKING PART IN THE STUDY BE KEPT CONFIDENTIAL?

The only purpose of this study is to assess the best way to rehabilitate patients after anterior cruciate ligament reconstruction surgery. The research team will keep your name, age, sex and your results in a record that will be stored on a password-protected computer to ensure only persons involved in the study can access the information. The storage and subsequent destruction of your data is compliant with the Data Protection Act 1998. All information that is collected about you during the course of the research will be kept strictly confidential. Any information about you that leaves this hospital will have your name and address removed so that you cannot be identified from it, and will subsequently be anonymous.

COMPLAINTS

If you believe you have been harmed in any way by taking part in this study, you have the right to pursue a complaint and seek any resulting compensation through the Queen Margaret University, Edinburgh and Robert Jones & Agnes Hunt NHS Orthopaedic Hospital, Oswestry, who are acting as the research sponsors. Details about this are available from the research team. Also, as an NHS patient, you have the right to pursue a complaint through the usual NHS complains procedures. Please note that the NHS has no legal liability for non-negligent harm. However, if you are harmed as a result of someone's negligence, you may have grounds for legal action against the NHS, but you may have to pay your legal costs.

CONTACT DETAILS FOR FURTHER INFORMATION:
We hope you will participate in this study, but if you have any questions or would like more information, please contact:

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Clinical Specialist Physiotherapist (Sports)
Physiotherapy Department
RJAH Orthopaedic & District NHS Trust
Gobowen
Oswestry
Shropshire
SY10 7AG

Christopher Yates
Chief Investigator, Research Team.
School of Health Sciences
Queen Margaret University, Edinburgh
Queen Margaret University Drive
Musselburgh
East Lothian
United Kingdom
EH21 6UU

WHO HAS REVIEWED THE STUDY?
For you to have been offered participation in this study, it will have had to have been already given a favourable ethical opinion for conduct in the NHS by the Staffordshire Research Ethics Committee (REC reference number 11WM0232) and by Queen Margaret University Edinburgh's local Ethics Committee. It will also have been approved for scientific merit by the Research Panel at Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry.

Thank you for taking the time to read this information sheet and considering whether or not you'd like to participate.

APPENDIX 11

Consent Form

Queen Margaret University
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School of Health Sciences
Queen Margaret University Drive
Musselburgh
East Lothian
EH21 6UU

The Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS Trust

National Centre for Sport Injury Surgery
Gobowen
Oswestry
Shropshire
SY10 7AG

PROJECT TITLE:

Effects of reconstruction surgery and individualised rehabilitation on neuromuscular, sensorimotor and musculoskeletal performance in patients with anterior cruciate ligament deficiency.

CONSENT FORM

1. I confirm that I have read and understand the information sheet provided for the above study.

I have had the opportunity to consider the information, ask any questions, and have had these answered satisfactorily.

2. I understand that my participation in this study is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

3. I understand that data collected during this study may be looked at by responsible individuals from the NHS (being Robert Jones and Agnes Hunt Orthopaedic & District Hospital, Oswestry) and Queen Margaret University throughout the course of this study.

4. I agree that the research team/physiotherapists may contact me by email, letter (telephone to discuss my rehabilitation progress should this be needed.

5. I agree to my GP being informed of my participation in the study.

6. I agree to take part in the above study.

Name of Participant Date Signature

Name of Researcher Date Signature

APPENDIX 12

TABLE 123 - Psychometric measurement characteristics of Patient-Based Outcome Measures (P-BOMs: IKDC, KOOS, and Lysholm), adapted from Collins et al., 2011).

	IKDC	KOOS	LYSHOLM
Purpose:	Designed to measure symptoms, function, and sports activity.	Evaluating short-term and long-terms symptoms and function.	Evaluate outcomes of knee ligament surgery, particularly symptoms of Instability.
Population & condition:	Ligament, meniscal, articular cartilage lesions, and patello-femoral injuries.	Young and middle-aged patients with injuries that may lead to post-traumatic OA (i.e., ACL, meniscal, or chondral injury).	Knee ligament injury and anteromedial, anterolateral, combined anteromedial/anterolateral, posterolateral rotatory, or straight posterior instability.
Content/ items:	18 items: (7-items for symptoms, 1-item for sport participation, 9-items for daily activities, and 1-item for current knee function).	42 items across 5 subscales: (1) pain frequency and severity during functional activities; (2) symptoms (i.e., stiffness and catching); (3) difficulty experienced ADL; (4) sport and recreational activities; and (5) knee-related QOL.	8 items: (1) limp, (2) support, (3) locking, (4) instability, (5) pain, (6) swelling, (7) stair climbing, and (8) squatting.
Response option/scale:	Items: 1, 4, 5, 7, 8 (yes/no); Items: 9 use 5-point Likert scales Items: 2, 3, and 10 use 11-point NRS.	5-point Likert scale.	Individual items are scored differently, using individual scoring scales: (1) limp [0, 3, 5]; (2) support [0, 2, 5]; (3) locking [0, 2, 6, 10, 15]; (4) instability [0, 5, 10, 15, 20, 25]; (5) pain [0, 5, 10, 15, 20, 25]; (6) swelling [0, 2, 6, 10]; (7) stair climbing [0, 2, 6, 10]; and (8) squatting [0, 2,4, 5].
Availability:	Freely available online	Freely available online.	Freely available.

	IKDC	KOOS	LYSHOLM
Scoring/ interpretation:	Ordinal method (i.e., 0 for responses that represent the highest level of symptoms or lowest level of function). Scores for each item are summed to give a total score (excluding item 10a). The total score is calculated as (sum of items)/ (maximum possible score) × 100, to give a total score of 100 [100 = no limitation with daily or sporting activities].	Each item is scored from 0-4 and transformed to a 0 - 100 scale [0 = extreme problems, and 100 = no problems].	Arbitrary score on an increasing scale. The total score is the sum of each response to the 8 items, of a possible score of 100 [100 = no symptoms or disability; scores categorised: excellent (95-100); good (84-94); fair (65-83), and poor (≤64)].
Patient administration time:	10 minutes.	10 minutes	Time to complete not been reported.
Time to evaluate:	Approximately 5-minutes (training is not necessary).	Approximately 5 minutes (training is not necessary).	Less than 5-minutes (training is not necessary).
Acceptability:	Studies consistently report no floor or ceiling effects.	Rates of missing data are low. Studies consistently report no or acceptable floor or ceiling effects in knee-injury cohorts.	There are consistent reports of no floor or ceiling effects.
Reliability:	Internal consistency is adequate for patients with knee injuries and mixed knee pathologies. Test-retest reliability is adequate for groups of patients with knee injuries and mixed pathologies and individuals with knee injuries. The minimal detectable change has been reported to be between 8.8 and 15.6, and the standard error of the measure between 3.2 and 5.6.	For patients with knee injuries, pain, ADL, and sport/recreation sub-scales have adequate internal consistency. While the symptom and QOL sub-scales have had reports of lower as well as adequate internal consistency. Across the 5 sub-scales, minimal detectable change ranges from 6-12 for knee injuries and from 13.4-21.1 for knee OA.	Appears to have inadequate internal consistency in patients with a variety of knee conditions. Test-retest reliability is adequate for use in groups with knee injuries, but is less than adequate for groups with mixed knee pathologies. Minimal detectable change has been reported as between 8.9 and 10.1 for knee injuries, while the standard error of the measure is reported to range from 3.2 to 3.6 for knee injuries and from 9.7 to 12.5 for mixed knee pathologies.

	IKDC	KOOS	LYSHOLM
Face and content validity:	The lack of patient contribution to the selection and revision of items in the IKDC means that content validity cannot necessarily be assumed.	As well as exhibiting face validity, the direct involvement of patients with knee conditions in the development of the KOOS facilitates content validity.	Face validity confirmed as evaluated by 5 orthopaedic surgeons with sports medicine experience. However, as Lysholm is surgeon derived, content validity from the patient's perspective cannot be assumed.
Construct validity:	High convergent and divergent construct validity (i.e., IKDC more strongly correlated with the SF-36: physical subscales and component summary than with the mental subscales and component summary, Cincinnati, pain (VAS), Oxford 12 questionnaire, WOMAC, Lysholm, and SF-36 physical component, physical function, and bodily pain subscales) found.	Multiple studies reported high convergent construct validity (i.e., SF-36).	Multiple studies reported high convergent construct validity (i.e., significant correlations with the HSS, Cincinnati, IKDC, Fulkerson and Kujala, WOMAC, Short Form 12 and Short Form 36 physical components than mental components).
Ability to detect change:	Appears to be a responsive measure of symptoms, function, and sports activity for patients with a variety of knee conditions. The minimum clinically important difference has been reported to be 6.3 at 6 months and 16.7 at 12 months following cartilage repair, and 11.5-20.5 (range 6-28 months) in those who have undergone various surgical procedures for mixed (various) knee pathologies.	Appears to be responsive to change in patients with a variety of conditions (non-surgical and surgical interventions). Large effect sizes found in all subscales 6-months ACL reconstruction. MCID and patient-acceptable symptom state (PASS) have not been calculated in any patient population.	Large effect sizes following ACL reconstruction (6-9 months post-surgery) with large effect sizes reported following 1-month physiotherapy in a group of patients with mixed knee pathologies. MCID and patient-acceptable symptom state (PASS) have not been calculated in any patient population.

APPENDIX 13

Descriptive data (means and standard deviations) for all P-BOMs and C-BOMs from Study 4 (Chapter 7: Intervention RCT investigation).

TABLE 124 - Group mean scores (± SD) for P-BOMs (VAS [Pain], IKDC, Lysholm, and Performance Profile (injured and non-injured limb) at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups with patients with unilateral ACL injury.

	CONTROL (CON) GROUP				
	VAS (Pain)	**IKDC**	**Lysholm**	**Performance Profile**	
				Injured	Non-injured
Pre-surgery	3.1 ± 2.0	64.5 ± 12.8	62.5 ± 14.2	4.2 ± 0.9	9.5 ± 0.2
6 weeks	4.0 ± 1.6	57.8 ± 7.4	67.7 ± 12.7	6.3 ± 1.0	9.6 ± 0.5
12 weeks	2.9 ± 1.3	76.7 ± 5.6	84.4 ± 11.8	8.6 ± 0.7	9.8 ± 0.3
24 weeks	1.0 ± 1.2	86.3 ± 6.4	87.6 ± 12.4	9.2 ± 0.3	9.8 ± 0.3

	PERFORMANCE PROFILE MANANAGEMENT (PPM) GROUP				
	VAS (Pain)	**IKDC**	**Lysholm**	**Performance Profile**	
				Injured	Non-injured
Pre-surgery	4.1 ± 1.9	61.5 ± 10.0	60.6 ± 15.8	4.3 ± 0.8	9.4 ± 0.5
6 weeks	3.6 ± 1.6	60.8 ± 13.4	70.3 ± 14.5	6.4 ± 0.9	9.6 ± 0.4
12 weeks	2.1 ± 2.0	78.2 ± 11.9	83.4 ± 13.9	8.6 ± 0.7	9.8 ± 0.2
24 weeks	0.7 ± 1.0	86.6 ± 11.8	86.4 ± 13.6	9.1 ± 0.5	9.8 ± 0.4

TABLE 125 - Group mean scores (± SD) for P-BOMs (KOOS sub-scale [symptom, pain, function, sport and recreation, and quality of life] scores) at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups with patients with unilateral ACL injury.

	CONTROL (CON) GROUP				
	KOOS sub-scale scores:				
	Symptoms	Pain	Function	Sport/rec	QoL
Pre-surgery	13.0 ± 3.7	10.6 ± 6.4	12.9 ± 12.4	12.0 ± 3.9	10.5 ± 2.5
6 weeks	12.1 ± 2.8	11.7 ± 3.2	15.9 ± 9.4	11.3 ± 5.6	9.5 ± 3.0
12 weeks	9.9 ± 2.5	5.6 ± 2.3	5.3 ± 4.0	6.9 ± 3.3	7.6 ± 2.5
24 weeks	9.1 ± 2.1	3.6 ± 3.7	3.3 ± 6.6	4.3 ± 3.5	4.3 ± 2.6

	PERFORMANCE PROFILE MANANAGEMENT (PPM) GROUP				
	KOOS sub-scale scores:				
	Symptoms	Pain	Function	Sport/rec	QoL
Pre-surgery	14.0 ± 3.2	10.1 ± 5.7	12.6 ± 11.2	10.3 ± 4.8	11.0 ± 3.2
6 weeks	12.1 ± 2.5	10.3 ± 3.1	14.2 ± 11.0	10.2 ± 6.7	9.4 ± 3.0
12 weeks	9.4 ± 2.4	5.2 ± 2.2	4.1 ± 4.6	6.0 ± 4.4	7.1 ± 2.1
24 weeks	9.2 ± 2.3	4.3 ± 3.5	4.3 ± 7.3	3.8 ± 3.8	7.2 ± 2.8

TABLE 126 - Group mean scores (± SD) for C-BOMs (Single-Leg Hop for distance) at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups with patients with unilateral ACL injury. **NOTE:** single-leg-hop for distance is contraindicated at week-06 (see p. 189 for explanation).

	CON		PPM	
	Injured	Non-Injured	Injured	Non-injured
Pre-surgery	113.6 ± 20.5	132.1 ± 19.0	118.1 ± 27.4	137.7 ± 35.9
6 weeks	-	127.1 ± 21.5	-	132.1 ± 32.0
12 weeks	105.1 ± 18.2	124.8 ± 18.8	121.2 ± 29.0	129.4 ± 34.4
24 weeks	115.7 ± 18.9	133.5 ± 19.5	128.8± 29.5	139.4 ± 33.2

Group mean scores (± SD) for C-BOMs (ATFD) at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups with patients with unilateral ACL injury.

	CON		PPM	
	Injured	Non-Injured	Injured	Non-injured
Pre-surgery	7.2 ± 1.2	3.4 ± 1.1	7.4 ± 1.5	3.2 ± 1.0
6 weeks	3.0 ± 1.1	2.9 ± 0.9	3.0 ± 1.4	3.0 ± 1.1
12 weeks	3.5 ± 0.7	2.9 ± 0.9	3.7 ± 1.4	2.8 ± 1.2
24 weeks	3.5 ± 0.6	2.9 ± 0.9	3.7 ± 1.2	2.9 ± 1.0

TABLE 127 - Group mean scores (± SD) for C-BOMs (SMP-FE) for the injured and non-injured limbs at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups associated with the knee flexors and extensors with patients with unilateral ACL injury.

	CON			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	108.1 ± 39.1	186.0 ± 68.8	123.3 ± 40.7	204.1 ± 68.0
6 weeks	95.0 ± 29.3	178.8 ± 71.8	119.3 ± 36.4	208.6 ± 64.5
12 weeks	117.4 ± 32.1	187.7 ± 45.3	130.9 ± 30.0	212.8 ± 54.6
24 weeks	108.0 ± 39.6	188.3 ± 68.0	125.5 ± 32.8	209.8 ± 61.7

	PPM			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	110.1 ± 30.7	186.2 ± 64.3	123.8 ± 42.7	205.6 ± 75.3
6 weeks	89.2 ± 22.4	176.0 ± 62.6	113.1 ± 39.1	207.9 ± 73.9
12 weeks	104.6 ± 30.7	185.4 ± 65.4	132.9 ± 47.6	206.1 ± 72.1
24 weeks	110.4 ± 31.4	185.1 ± 62.1	126.2 ± 45.1	211.0 ± 75.8

TABLE 128 - Group mean scores (± SD) for C-BOMs (Peak force, PF) with the injured and non-injured limbs at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups associated with the knee flexors and knee extensors with patients with unilateral ACL injury.

	CONTROL (CON) GROUP			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	180.1 ± 60.5	324.0 ± 96.8	223.4 ± 64.9	400.8 ± 85.2
6 weeks	145.6 ± 57.8	237.0 ± 80.2	225.3 ± 56.3	349.1 ± 79.2
12 weeks	160.6 ± 52.2	277.1 ± 80.8	224.9 ± 53.9	359.6 ± 81.1
24 weeks	179.2 ± 56.3	318.4 ± 93.6	229.8 ± 55.1	390.0 ± 83.6

	PERFORMANCE PROFILE MANANAGEMENT (PPM) GROUP			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	183.6 ± 41.8	358.2 ± 90.8	211.0 ± 69.9	428.1 ± 98.4
6 weeks	139.8 ± 41.4	259.0 ± 84.4	224.8 ± 61.9	392.8 ± 94.7
12 weeks	158.2 ± 39.6	302.5 ± 82.8	223.5 ± 60.9	393.7 ± 92.7
24 weeks	187.4 ± 60.5	359.7 ± 99.6	243.4 ± 90.1	437.9 ± 98.5

TABLE 129 - Group mean scores (± SD) for C-BOMs (Electromechanical delay, EMD) for the injured and non-injured limbs at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups associated with the knee flexors and knee extensors with patients with unilateral ACL injury.

	CON			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	29.8 ± 3.5	32.0 ± 7.1	34.6 ± 8.3	37.1 ± 6.8
6 weeks	39.9 ± 4.9	40.7 ± 7.3	34.2 ± 6.8	37.5 ± 4.4
12 weeks	37.1 ± 3.4	35.8 ± 4.8	36.1 ± 5.4	36.8 ± 3.9
24 weeks	33.5 ± 4.2	31.8 ± 6.1	35.0 ± 5.4	35.7 ± 8.5

	PPM			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	29.5 ± 3.9	31.9 ± 4.5	36.7 ± 7.1	36.7 ± 5.8
6 weeks	40.9 ± 4.1	41.8 ± 4.8	36.1 ± 3.8	36.5 ± 5.9
12 weeks	36.4 ± 3.1	36.0 ± 3.8	35.9 ± 4.2	35.7 ± 4.1
24 weeks	32.8 ±7.9	32.5 ± 5.7	34.8 ± 9.1	37.0 ± 6.8

TABLE 130 - Group mean scores (± SD) for C-BOMs (Rate of force development, RFD) for the injured and non-injured limbs at pre-surgery, 6, 12, and 24 weeks post-surgery for Performance Profile management and contemporary rehabilitation groups associated with the knee flexors and extensors with patients with unilateral ACL injury.

	CONTEMPORARY			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	942.4 ± 476.0	1682.2 ± 651.4	1071.3 ± 421.0	2469.2 ± 902.8
6 weeks	563.7 ± 418.2	1416.2 ± 466.9	873.7 ± 391.9	2389.9 ± 858.2
12 weeks	690.6 ± 348.0	1592.0 ± 660.2	995.2 ± 373.5	2475.1 ± 842.4
24 weeks	965.4 ± 509.2	1620.8 ± 690.1	915.8 ± 575.6	2385.0 ± 923.7

	PERFORMANCE PROFILE MANAGEMENT			
	Injured		**Non-injured**	
	Flexors	Extensors	Flexors	Extensors
Pre-surgery	827.4 ± 444.2	1514.6 ± 835.5	922.0 ± 360.1	2385.0 ± 1221.4
6 weeks	577.8 ± 525.7	1271.2 ± 463.6	775.5 ± 300.1	2251.2 ± 1126.0
12 weeks	749.6 ± 472.2	1478.9 ± 793.8	776.9 ± 320.2	2320.8 ± 1160.0
24 weeks	871.9 ± 480.8	1421.9 ± 613.9	819.5 ± 606.6	2099.7 ± 1077.3

APPENDIX 14

TABLE 131 - Intention to Treat outcome data: Comparisons using univariate ANOVA of group mean responses for P-BOMs (VAS [Pain], IKDC, Lysholm, KOOS, and Performance Profile) and C-BOMs (Single-Leg Hop for distance, ATFD, PF, RFD, EMD, and SMP-FE) at pre-surgery (baseline) assessment occasion among Lost to follow-up (n = 12), experimental (PPM) (n = 23), and control (CON) (n = 23) (n = 23) rehabilitation groups, respectively.

Patient-Based Outcome Measures (P-BOMs)

	Pre-surgery	**PPM**	**CON**	**OUTCOME**
VAS (Pain)	4.1 ± 2.0	4.1 ± 1.9	4.4 ± 1.8	$F_{(264)}$ = 0.9, ns
IKDC	64.5 ± 12.8	61.5 ± 10.0	62.2 ± 11.1	$F_{(264)}$ = 1.2, ns
Lysholm	62.5 ± 14.2	60.6 ± 15.8	62.2 ± 14.9	$F_{(264)}$ = 1.4, ns
KOOS (sub-scale):				
Symptoms	13.0 ± 3.7	14.0 ± 3.2	13.4 ± 3.5	$F_{(264)}$ = 0.,9 ns
Pain	10.6 ± 6.4	10.1 ± 5.7	6.2 ± 6.0	$F_{(264)}$ = 0.8, ns
Function	12.9 ± 12.4	12.6 ± 11.2	12.4 ± 11.4	$F_{(264)}$ = 0.6, ns
Sport/rec	12.0 ± 3.9	10.3 ± 4.8	12.4 ± 4.2	$F_{(264)}$ = 1.2, ns
QoL	10.5 ± 2.5	11.0 ± 3.2	11.2 ± 3.0	$F_{(264)}$ = 1.0, ns
Performance Profile:				
Injured limb	4.2 ± 0.9	4.3 ± 0.8	42.4 ± 0.8	$F_{(264)}$ = 0.9, ns
Non-Injured limb	9.5 ± 0.2	9.4 ± 0.5	9.5 ± 0.4	$F_{(264)}$ = 0.7, ns

Clinician-Based Outcome Measures (C-BOMs)

	Pre-surgery	PPM	CON	OUTCOME
Single-Leg Hop for distance:				
Injured limb	113.6 ± 20.5	128.1 ± 27.4	117.2 ± 18.4	$F_{(264)}$=0.7, ns
Non-Injured limb	132.1 ± 19.0	137.7 ± 35.9	131.8 ± 128.8	$F_{(264)}$ = 0.9, ns
ATFD:				
Injured limb	7.2 ± 1.2	7.4 ± 1.5	7.2 ± 1.2	$F_{(264)}$=1.0, ns
Non-Injured limb	3.4 ± 1.1	3.2 ± 1.0	3.3 ± 1.2	$F_{(264)}$ = 0.9, ns
SMP-FE:				
Flexors Injured limb	108.1 ± 39.1	110.1 ± 30.7	107.4 ± 25.2	$F_{(264)}$ = 1.4, ns
Extensors Injured limb	186.0 ± 68.8	186.2 ± 68.3	176.5 ± 54.2	$F_{(264)}$ = 1.5, ns
Flexors Non-Injured limb	123.3 ± 40.7	123.8 ± 42.7	120.3 ± 40.1	$F_{(264)}$ = 1.2, ns
Extensors Non-Injured limb	204.1 ± 68.0	205.6 ± 75.3	201 ± 54.8	$F_{(264)}$ = 1.4, ns
PF:				
Flexors Injured limb	180.1 ± 60.5	183.6 ± 41.8	181.3 ± 45.9	$F_{(264)}$ = 0.9, ns
Extensors Injured limb	324.0 ± 96.8	358.2 ± 90.8	315.4 ± 84.1	$F_{(264)}$= 0.9, ns
Flexors Non-Injured limb	233.9 ± 57.0	231.5 ± 62.9	232.5 ± 54.8	$F_{(264)}$ = 0.9, ns
Extensors Non-Injured limb	233.9 ± 57.0	231.5 ± 62.9	228.9 ± 47.4	$F_{(264)}$ = 0.8, ns
RFD:				
Flexors Injured limb	942.4 ± 476.0	827.4 ± 444.2	855.3 ± 433.2	$F_{(264)}$ = 0.6, ns
Extensors Injured limb	1682.2 ± 651.4	1514.6 ± 835.5	1543.9 ± 765.4	$F_{(264)}$ = 0.7, ns
Flexors Non-Injured limb	1071.3 ± 421.0	922.0 ± 360.1	901.8 ± 42.5	$F_{(264)}$ = 0.6, ns
Extensors Non-Injured limb	2469.2 ± 902.8	2385.0 ± 1221.4	2241.2 ± 888.4	$F_{(264)}$ = 0.7, ns
EMD:				
Flexors Injured limb	29.8 ± 3.5	29.5 ± 3.9	29.4 ± 3.2	$F_{(264)}$ = 0.6, ns
Extensors Injured limb	32.0 ± 7.1	31.9 ± 4.5	31.4 ± 5.4	$F_{(264)}$ = 0.9, ns
Flexors Non-Injured limb	34.6 ± 8.3	36.7 ± 7.1	32.5 ± 6.4	$F_{(264)}$ = 0.9, ns
Extensors Non-Injured limb	37.1 ± 6.8	36.7 ± 5.8	36.9 ± 4.3	$F_{(264)}$ = 0.1, ns

APPENDIX 15

Changes in P-BOMs (VAS [Pain], KOOS sub-scales (Pain, Symptoms, Function, Sport/rec, and QoL), and Lysholm) and C-BOMs (ATFD, PF, EMD, and RFD) at pre-surgery, and 6, 12, and 24 weeks post-ACLR surgery.

Patient-Based Outcome Measures

VAS (Pain)

Descriptive statistics (mean and standard deviation) for the VAS (Pain) are presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group condition (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for VAS (Pain). The group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effect on VAS (Pain) scores over time (PPM management: pre-ACLR surgery versus 24-week post-ACLR surgery (4.1 ± 1.9 versus 0.7 ± 1.0) (82.9% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (3.1 ± 2.0 versus 1.0 ± 1.2) (67.7% gain in performance) with no rehabilitation group indicating superiority in gaining performance capability [$F_{(1.1,50.2)} = 1.1$; *ns*][152] **(**

FIGURE 34; p. 332**)**.

Lysholm (Lysholm) Knee Score

Descriptive statistics (mean and standard deviation) for the Lysholm Knee Score is presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group (PPM; CON) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for Lysholm. The group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effect on Lysholm scores over time (PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (60.6 ± 15.8 versus 86.4 ± 13.6) (42.2% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (62.5 ± 14.2 versus 87.6 ± 12.4) (40.2% gain in performance) with no rehabilitation group condition indicating superiority in gaining performance capability[$F_{(2.5,110.2)GG} = 0.29$; *ns*] **(FIGURE 38**; p. 333**).**

Knee Injury and Osteoarthritis Outcome Score (KOOS)

Descriptive statistics (mean and standard deviation) associated with KOOS sub-scales (Symptoms, Pain, Function, Sport and Recreation, and QoL) scores are presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group (PPM;

[152] ns; non-significant (p> 0.05).

CON) by assessment occasion (pre-ACLR surgery, 6, 12, and 24 weeks post-ACLR surgery) interaction for all KOOS sub-scales scores. The group mean scores associated with the PPM and CON rehabilitation groups demonstrated congruency of effect on KOOS sub-scales (Symptoms: [PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (14.0 ± 3.2 versus 9.2 ± 2.3) (34.3% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (13.0 ± 3.7 versus 9.1 ± 2.1) (30.0% gain in performance)] [$F_{(3,132)}$=0.9; *ns*], Pain: [PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (10.1 ± 5.7 versus 4.3 ± 3.5) (57.4% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (10.6 ± 6.4 versus 3.6 ± 3.7) (66.0% gain in performance)] [$F_{(3,132)}$= 0.5; *ns*], Function: [PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (12.6 ± 11.2 versus 4.3 ± 7.3) (65.9% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (12.9 ± 12.4 versus 3.3 ± 6.6) (74.4% gain in performance)] [$F_{(3,132)}$= 0.7; *ns*], Sport and Recreation: [PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (10.3 ± 4.8 versus 3.8 ± 3.8) (63.1% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (12.0 ± 3.9 versus 4.3 ± 3.5) (64.2% gain in performance)] [$F_{(3,132)}$= 0.3; *ns*], and QoL: [PPM: pre-ACLR surgery versus 24 weeks post-ACLR surgery (11.0 ± 3.2 versus 7.2 ± 2.8) (34.5% gain in performance); CON: pre-ACLR surgery versus 24 weeks post-ACLR surgery (10.5 ± 2.5 versus 4.3 ± 2.6) (59.0% gain in performance)] [$F_{(3,132)}$= 0.9; *ns*]) scores over time with no rehabilitation group condition indicating superiority of capability **(FIGURE 38**; p. 333**).**

KOOS sub-scale (Pain) score

Testing of an *a priori*' difference' hypothesis of greater progressive increases in KOOS sub-scale (Pain) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (10.1 ± 5.7 versus 5.2 ± 2.2 units; 10.6 ± 6.4 versus 5.6 ± 2.3 units) and 24 weeks post-ACLR surgery (10.1 ± 5.7 versus 4.3 ± 3.5 units; 10.6 ± 6.4 versus 3.6 ± 3.7 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, of 48.5% and 47.2% for pre-surgery versus 12 weeks post-ACLR surgery, and 57.4% and 66.0% for pre-surgery versus 24 weeks post-ACLR surgery, respectively[$F_{(2.4,105.6)GG}$ = 36.3; $p< 0.05$] **TABLE** ; p. 342**).**

KOOS sub-scale (Function) score

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in KOOS sub-scale (Function) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (12.6 ± 11.2 versus 4.1 ± 4.6 units; 12.9 ± 12.4 versus 5.3 ± 4.0 units) and 24 weeks post-ACLR surgery (12.6 ± 11.2 versus 4.3 ± 7.3 units; 12.9 ± 12.4 versus 3.3 ± 6.6 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, of 67.5% and 58.9% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 65.9% and 74.4% for pre-surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(1.8,81.3)GG}$ = 27.4; $p < 0.0005$] **(FIGURE 38**; p. 333**).**

KOOS sub-scale (Sport and Recreation) score

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in KOOS sub-scale (sport/rec) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (10.3 ± 4.8 versus 6.0 ± 4.4 units; 12.0 ± 3.9 versus 6.9 ± 3.3 units) and 24 weeks post-ACLR surgery (10.3 ± 4.8 versus 3.8 ± 3.8 units; 12.0 ± 3.9 versus 4.3 ± 3.5 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, of 41.7% and 42.5% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 63.1% and 64.2% for pre-ACLR surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(3,132.0)}$= 31.5; $p < 0.0005$] **(FIGURE 38**; p. 333**).**

KOOS sub-scale (QoL) Score

Testing of an *a priori* 'difference' hypothesis of greater progressive increases in KOOS sub-scale (Quality of Life) score suggested that the effects of rehabilitation between PPM and CON rehabilitation groups at pre-ACLR surgery (baseline) and at assessment occasion 12 weeks post-ACLR surgery (11.0 ± 3.2 versus 7.1 ± 2.1 units; 10.5 ± 2.5 versus 7.6 ± 2.5 units) and 24 weeks post-ACLR surgery (11.0 ± 3.2 versus 7.2 ± 2.8 units; 10.5 ± 2.5 versus 4.3 ± 2.6 units) contributed most to the overall significant interaction, and gains for the PPM and CON rehabilitation groups, respectively, of 35.5% and 27.6% for pre-ACLR surgery versus 12 weeks post-ACLR surgery, and 34.5% and 59.0% for pre-ACLR surgery versus 24 weeks post-ACLR surgery, respectively [$F_{(1.4,65.2)GG}$= 7.9; $p < 0.002$] **(FIGURE 38**; p. 333**).**

Clinician-Based Outcome Measures

Anterior Tibio-Femoral Displacement (ATFD)

Descriptive statistics (mean and standard deviation) for the ATFD associated with the injured and non-injured limbs are presented in **APPENDIX 13** (p. 580). Analysis of variance (ANOVA) with repeated measures showed non-significant group condition (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction for ATFD the injured and non-injured limbs. The group mean scores associated with injured limb for the PPM and CON rehabilitation groups demonstrated congruency of effect on ATFD (injured leg) scores over time (PPM: pre-surgery versus 24-week (7.4 ± 1.5 versus 3.7 ± 1.2) (50.0% gain in performance); CON: pre-surgery versus 24-week (7.2 ± 1.2 versus 3.5 ± 0.6) (51.4% gain in performance) with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(1.6,73.3)GG}$= 0.3; ns].

Similarly, the group mean scores associated with non-injured limb for the PPM and CON rehabilitation groups remained relatively constant (PPM: pre-surgery versus 24-week (3.2 ± 1.0 versus 2.9 ± 1.0) (9.4% gain in performance); CON: pre-surgery versus 24-week (3.4 ± 1.1 versus 2.9 ± 0.9) (14.7% gain in performance) throughout all assessment occasions with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(1.6,73.3)GG}$= 0.3; ns].

Despite the lack of a significant three-way interactions (as above), further two-way ANOVA revealed a significant leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction [$F_{(1.7, 73.5)GG}$= 100.9; $p< 0.05$]. This suggested that the ATFD evaluated by the injured and non-injured legs irrespective of rehabilitation group condition were significantly different among the injured and non-injured limbs over time.

Peak Force (PF)

Descriptive statistics (mean and standard deviations) for Peak Force (PF) with the injured and non-injured limbs associated with the knee flexors and knee extensor musculature are presented **(**see **APPENDIX 13** [p. 580]**)**. Analysis of variance (ANOVA) with repeated measures showed non-significant group conditions (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction for PF associated with the knee flexors [$F_{(2.4, 105.6)GG}$=0.8; *ns*].

The group mean scores of the knee flexors of the injured and non-injured limbs associated with the PPM rehabilitation group condition (pre-surgery [baseline] versus 24-week (183.6 ± 41.8 versus 187.4 ± 60.5) [2.1% gain in performance] and CON rehabilitation groups (180.1 ± 60.5 versus 179.2 ± 56.3) [-0.5% loss in performance] demonstrated congruency of effect on PF over time with no group condition indicating superiority of capability. Similarly, the group mean scores of the knee extensors of the injured and non-injured limbs associated with the PPM (358.2 ± 90.8 versus 359.7 ± 99.6) [0.4% gain in performance] and CON rehabilitation group (324 ± 96.8 versus 318.4 ± 93.6) [1.7% loss in performance] conditions demonstrated similar congruency of effect on Peak Force over time [$F_{(2.0, 88.5)GG}$= 1.2; *ns*].

Despite the lack of a hypothesised significant three-way interactions (as above), further two-way ANOVA revealed a significant leg (injured; non-injured) by assessment occasions (pre-surgery, 6, 12, and 24 weeks post-surgery); suggesting that the injured and non-injured limbs over the assessment occasions (pre-surgery, 6, 12, and 24 weeks post-surgery), irrespective of rehabilitation groups were significantly different for the knee flexors [$F_{(1.5, 66.5)GG}$= 461.9; $p< 0.0005$] and knee extensors [$F_{(2.0, 88.5)GG}$= 19.3; $p< 0.0005$].

Electromechanical Delay (EMD)

Descriptive statistics (mean and standard deviation) for EMD are presented in **APPENDIX 13** (p. 580) for the knee flexors and knee extensors. Analysis of variance (ANOVA) with repeated measures showed non-significant group condition (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction for RFD. The group mean scores associated with knee extensors of the injured leg for the PPM and CON rehabilitation groups demonstrated congruency of effect on RFD scores over time (PPM: pre-surgery versus 24-week (31.9 ± 4.5 versus 32.5 ± 5.7) (1.8% loss in performance); CON: pre-surgery versus 24-week (32.0 ± 7.1 versus 31.8 ± 6.1) (~ 0.1% gain in performance) with no single rehabilitation group condition indicating superiority in gaining performance capability during patients' recovery [$F_{(3,132)}$= 0.53; *ns*].

Similarly, the group mean scores for EMD associated with the knee flexors of the injured and non-injured limbs showed similar patterns of recovery during rehabilitation compared to those of the knee extensors, with PPM and CON rehabilitation groups showing equivalent post-surgery gains in performance compared to baseline (~ 0.3%) [$F_{(1.6,\ 73.3)GG}$= 0.42; ns].

Rate of Force Development (RFD)

Descriptive statistics (mean and standard deviation) for RFD is presented in **APPENDIX 13** (p. 580) for the knee flexors and knee extensors. Analysis of variance (ANOVA) with repeated measures showed non-significant group condition (PPM; CON) by leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction for RFD. The group mean scores associated with knee extensors for the PPM and CON rehabilitation groups demonstrated congruency of effect on RFD scores over time (PPM: pre-surgery versus 24-week (1514.6 ± 835.5 versus 1421.93± 613.9) (50.0% gain in performance); CON: pre-surgery versus 24-week (1682.2 ± 651.4 versus 1620.8 ± 690.1) (51.4% gain in performance) with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(3,132)}$= 0.43; *ns*].

Similarly, the group mean scores associated with non-injured limb for the PPM and CON rehabilitation groups remained relatively constant (PPM: pre-surgery versus 24-week (3.2 ± 1.0 versus 2.9 ± 1.0) (9.4% gain in performance); CON: pre-surgery versus 24-week (3.4 ± 1.1 versus 2.9 ± 0.9) (14.7% gain in performance) throughout all assessment occasions with no rehabilitation group condition indicating superiority in gaining performance capability [$F_{(1.6,73.3)GG}$= 0.3; ns].

Despite the lack of a significant three-way interactions (as above), further two-way ANOVA revealed a significant leg (injured; non-injured) by assessment occasion (pre-surgery, 6, 12, and 24 weeks post-surgery) interaction [$F_{(1.7,\ 73.5)GG}$= 100.9; $p < 0.05$]. This suggested that the ATFD evaluated by the injured and non-injured legs irrespective of rehabilitation group condition were significantly different among the injured and non-injured limbs over time.